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for the period  
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to June 1990

## **Review of Cryogenic Mechanical and Thermal Properties of Al-Li Alloys and Alloy 2219**

September 1990

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*Prepared for the:* **Astronautics Laboratory (AFSC)**  
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Air Force Systems Command  
Edwards AFB CA 93523-5000

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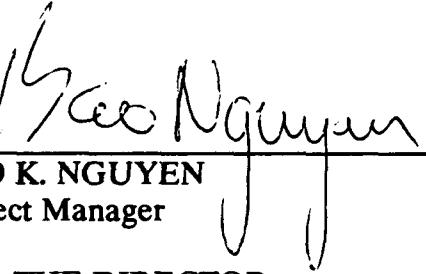
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## FOREWORD

This final report was submitted by National Institute of Standards and Technology, Boulder CO on completion of contract AL 99011 with the Astronautics Laboratory (AFSC), Edwards AFB CA. AL Project Managers were Bao Nguyen and Lt Bruce Pham.

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the DD Form 1473.

  
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Since the purpose of the NIST program has been to assess the relative suitability of high-strength Al-Li alloys and alloy 2219 for use in ALS cryogenic tanks, data on Al-Li alloys 8090, 2090, Weldalite <sup>TM</sup> 049, and Al alloy 2219 have been included in the survey. Properties covered in this survey are tensile strength, yield strength, elongation, fracture toughness, elastic constants, specific heat, thermal conductivity, and thermal expansion.												
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## **EXECUTIVE SUMMARY**

The review of cryogenic mechanical and thermal properties presented here is part of a broader National Institute of Standards and Technology (NIST) program to assess new high-strength Al-Li alloys for use in the cryogenic tankage of the Advanced Launch System (ALS). This program is sponsored by the Air Force Systems Command, Astronautics Laboratory, Edwards Air Force Base, with Bao Nguyen, Task Manager. It is part of the Materials and Process Validation (3101) of the Structures, Materials, and Manufacturing (3000) portion of the ALS Advanced Development Program.

Since the purpose of the NIST program has been to assess the relative suitability of high-strength Al-Li alloys and alloy 2219 for use in ALS cryogenic tanks, data on Al-Li alloys 8090, 2090, WL049,\* and Al alloy 2219 have been included in the survey. A table of alloy composition limits follows this introduction. Properties covered in this survey are tensile strength, yield strength, elongation, fracture toughness, elastic constants, specific heat, thermal conductivity, and thermal expansion.

\* The WL049 alloy does not have a generic specification at this time, and is commonly termed WELDALITE 049. Trade names are furnished to identify the material adequately. Such identification does not imply recommendation or endorsements by NIST, nor does it imply that the materials identified are necessarily the best available for the purpose.

Composition Limits for Al-Li Alloys and Alloy 2219 in wt%.

Elements	ALLOY			
	8090	2090	WL049	2219
Cu	1.0-1.6	2.4-3.0	4.0-6.3	5.8-6.8
Li	2.2-2.7	1.9-2.6	1.3	--
Mg	0.6-1.3	0.25	0.4	0.02
Zr	0.04-0.16	0.08-0.15	0.14	0.10-0.25
Si	0.20	0.10	--	0.20
Fe	0.30	0.12	--	0.30
Ti	0.10	0.15	0.03	0.02-0.10
Cr	0.10	0.05	--	--
Zn	0.25	0.10	--	0.10
Ag	--	--	0.4	--
Mn	0.10	0.05	--	0.20-0.40
Others, each	0.05	0.05	--	--
Others, total	0.15	0.15	--	--
Al	Remainder	Remainder	Remainder	Remainder

## 1. TENSILE PROPERTIES

### 1.1. Introduction to Graphs

In general, only measurement sets that included cryogenic data were included in the graphs and tables. However, some ambient temperature values, such as the producers' typical values, are presented. The horizontal scale of the graphs was extended to 600 K because some cryogenic data sets also included measurements at temperatures above ambient and it was considered useful to present the additional information. When available, data are provided in the following orientations: longitudinal (L), transverse (T), 45° from the rolling direction, and through-thickness (S). The graphs show data for the T8 temper for all the alloys. Additional graphs are provided for the T3 temper for alloys 8090, WL049, and 2219, and the T6 temper for alloy WL049. The graphs are organized in descending order by temper for each alloy.

All tensile property data points shown graphically are listed and referenced in the tables following the graphs. A reference number is provided in the legend of each graph. Two formats are used in the tensile property tables: 1) data, and 2) test parameters, including further documentation. The data tables present temperature and tensile properties, including reduction of area (not presented in the graphs). This is followed by information on orientation, temper, product form and thickness, thermomechanical processing, grain size, hardness, number of tests per data point, and a reference and note number. The reference and note number (which corresponds to the reference number on the graphs) is a guide to the accompanying test parameter table. The test parameter table gives information on the strain rate during testing; specimen type, dimensions, and location; exposure time at test temperature (available chiefly for data above ambient temperature); supplier; year produced; lot number; product dimensions; and chemistry. Note that the tables are ordered by temper, starting with T8 tempers and ending with T3 or annealed (O) tempers for each orientation. Some cryogenic data is presented in the tables but not in the graphs; for example, data on the T4 temper of alloy 2090. A list of comments follows the tensile data table and the test parameter table for each alloy where necessary.

Much of the cryogenic data, especially on current production vintages and tempers, are from recent measurements at the National Institute of Standards and Technology (NIST), under sponsorship of the Advanced Launch System (ALS) program. A forthcoming report<sup>1</sup> includes more detailed information on measurement techniques, stress-strain curves, and microstructure. The NIST data are denoted by solid square and solid diamond symbols on the graphs. A smoothed line connects the NIST data points corresponding to tempers under consideration for use in the ALS program. The position of the line and the indicated temperature dependence generally are based on measurements made on two specimens at 4, 20, 76, and 295 K. The material in the NIST program was usually 12.7-mm (0.5-in) plate; and only ultimate tensile strength measurements were obtained from tests in the S orientation.

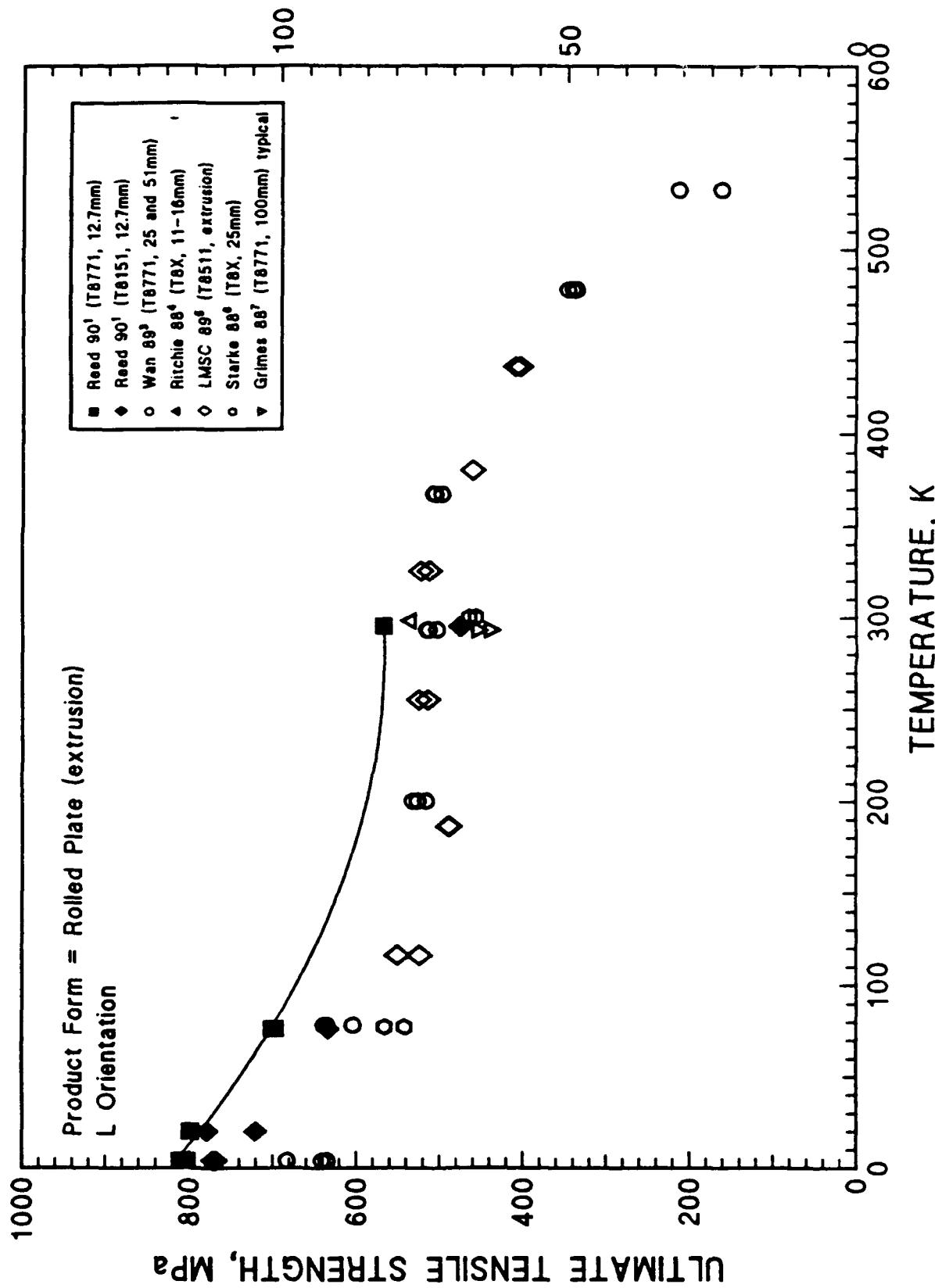
The four graphs of alloy 2219-T8 data in the L and T orientations for tensile yield strength and ultimate tensile strength include dashed lines. These lines, labeled MIL-HNBK-5E, were derived from curves presented in Figures 3.2.6.41(a) and (b) of that handbook<sup>2</sup> which give cryogenic values as a percentage of the room temperature value for ultimate and yield strengths.

respectively. The room temperature values used to obtain the curves on our graphs for ultimate and yield strengths came from Table 3.2.6.0(b) in the MIL-HNBK-5E handbook. These values are "A basis" minimums and indicate that 99% of the data should fall on or above the curve, with a confidence level of 95%. (Please note that this information is also provided on the graphs by the asterisked footnote.)

It is apparent that 99% of the cryogenic data do not fall on or above the handbook-derived minimum line for temper T87. We do not have a complete explanation for why this occurred. It is to be expected that the solid squares, temper T851, consistently would fall below the line. Very thick plate results frequently fall below the line. The "A basis" value does not pertain to plates of these thicknesses. At thicknesses of 100-125 mm the "A basis" line would fall 21 and 14 MPa lower for ultimate and yield strengths, respectively, in the T orientation. No value is provided for thicker plate in the L orientation.

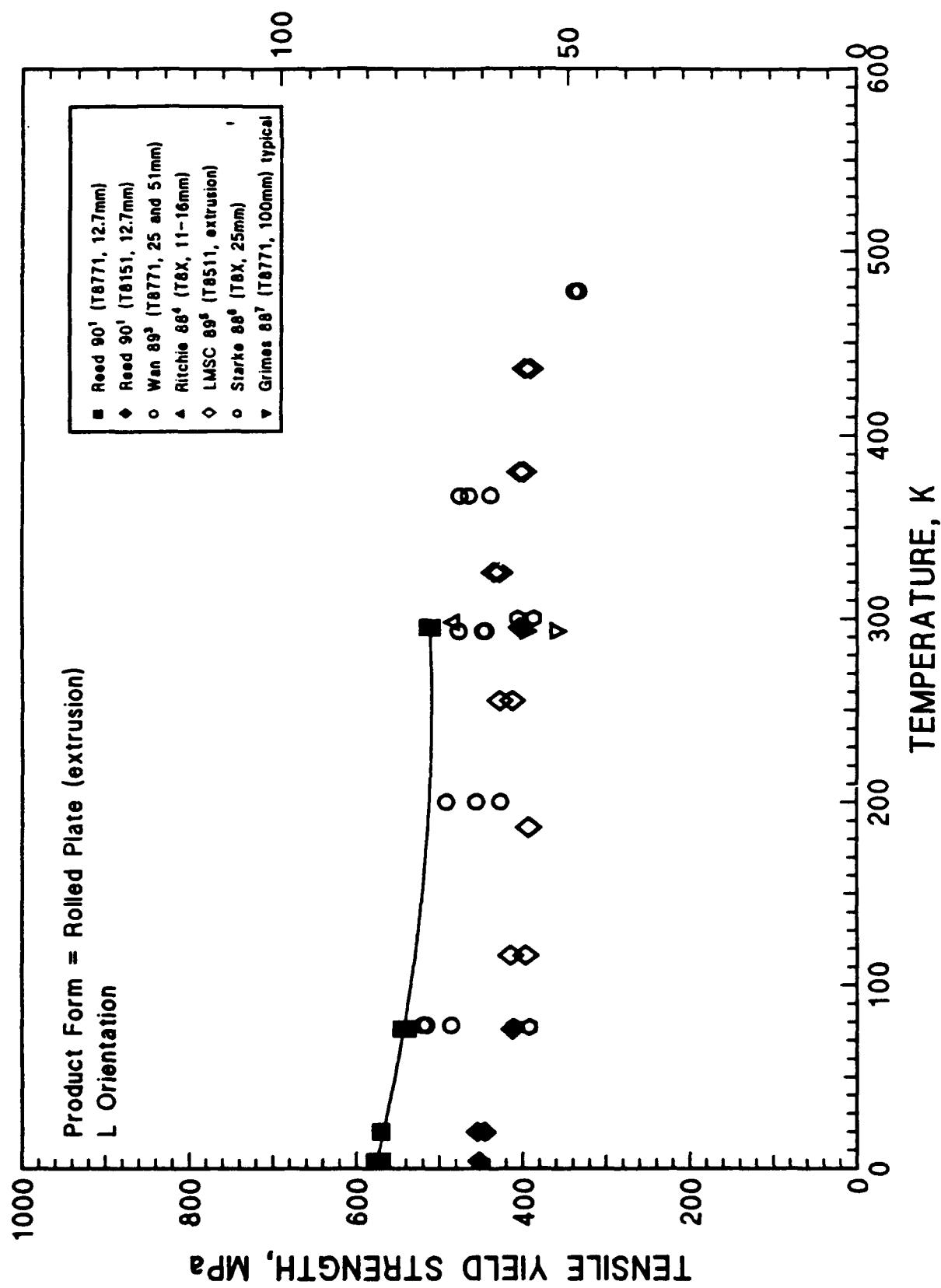
8090-T8

## ULTIMATE TENSILE STRENGTH, ksi



8090-T8

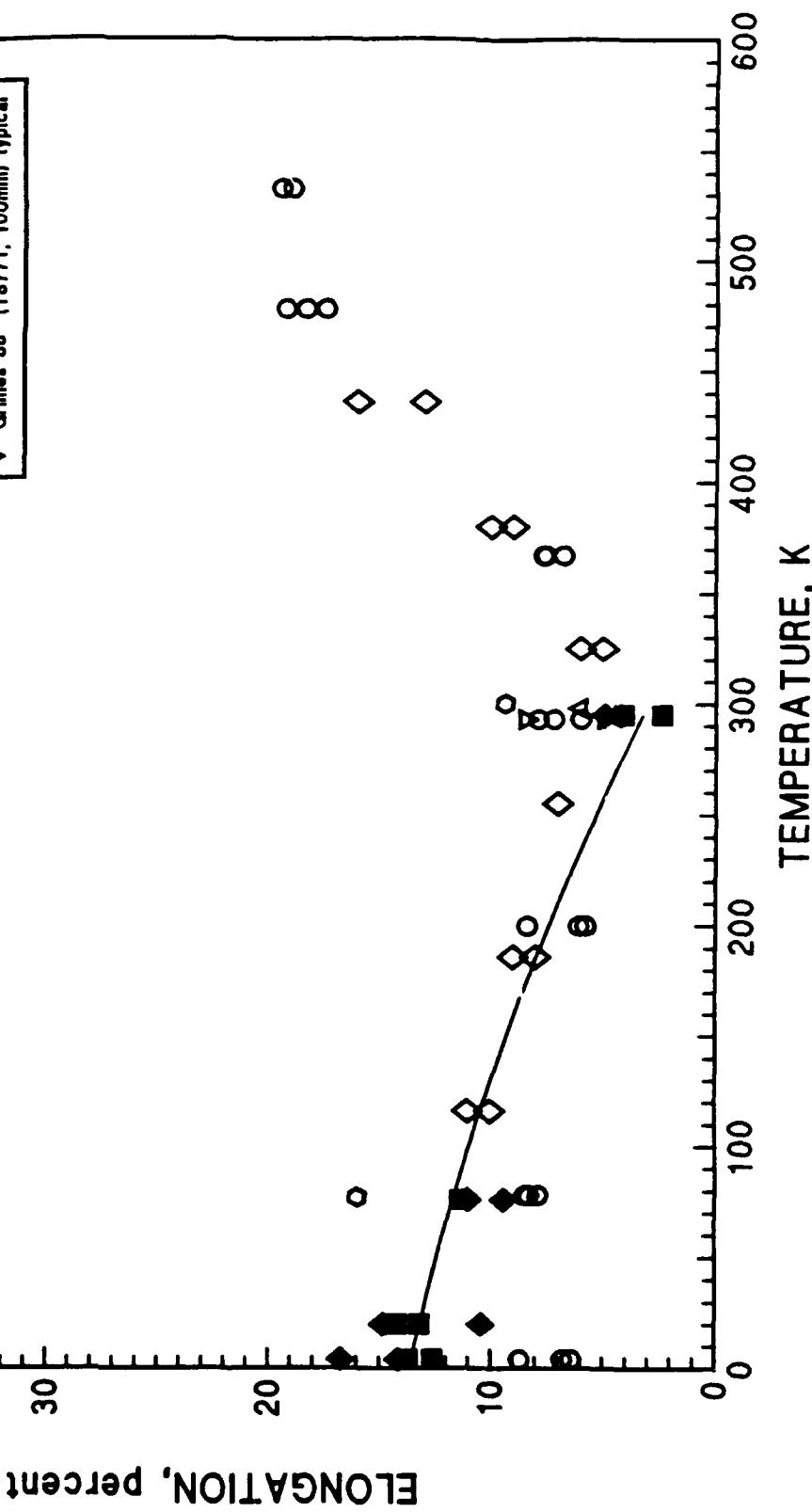
## TENSILE YIELD STRENGTH, ksi



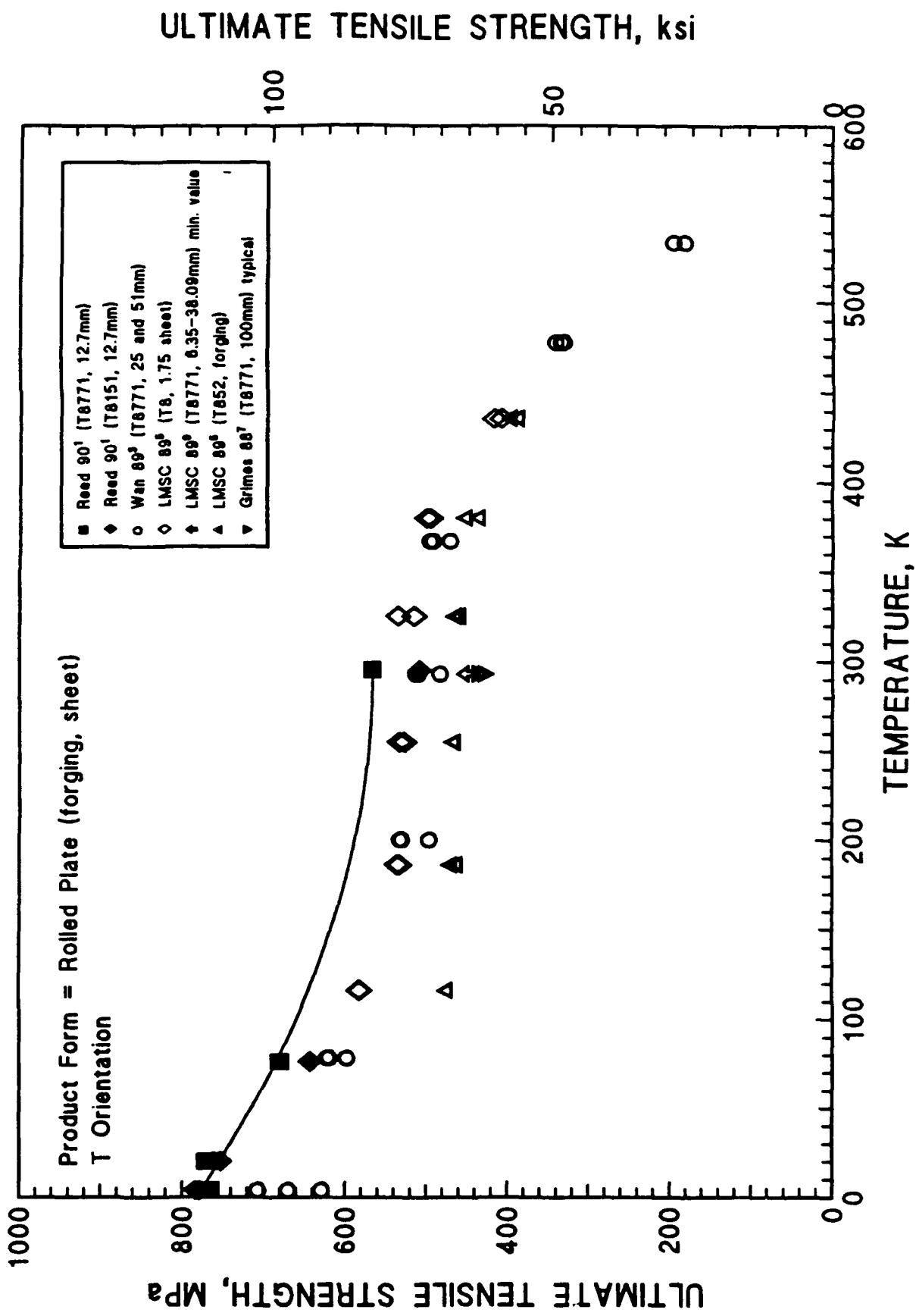
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Product Form = Rolled Plate (extrusion)  
 L Orientation

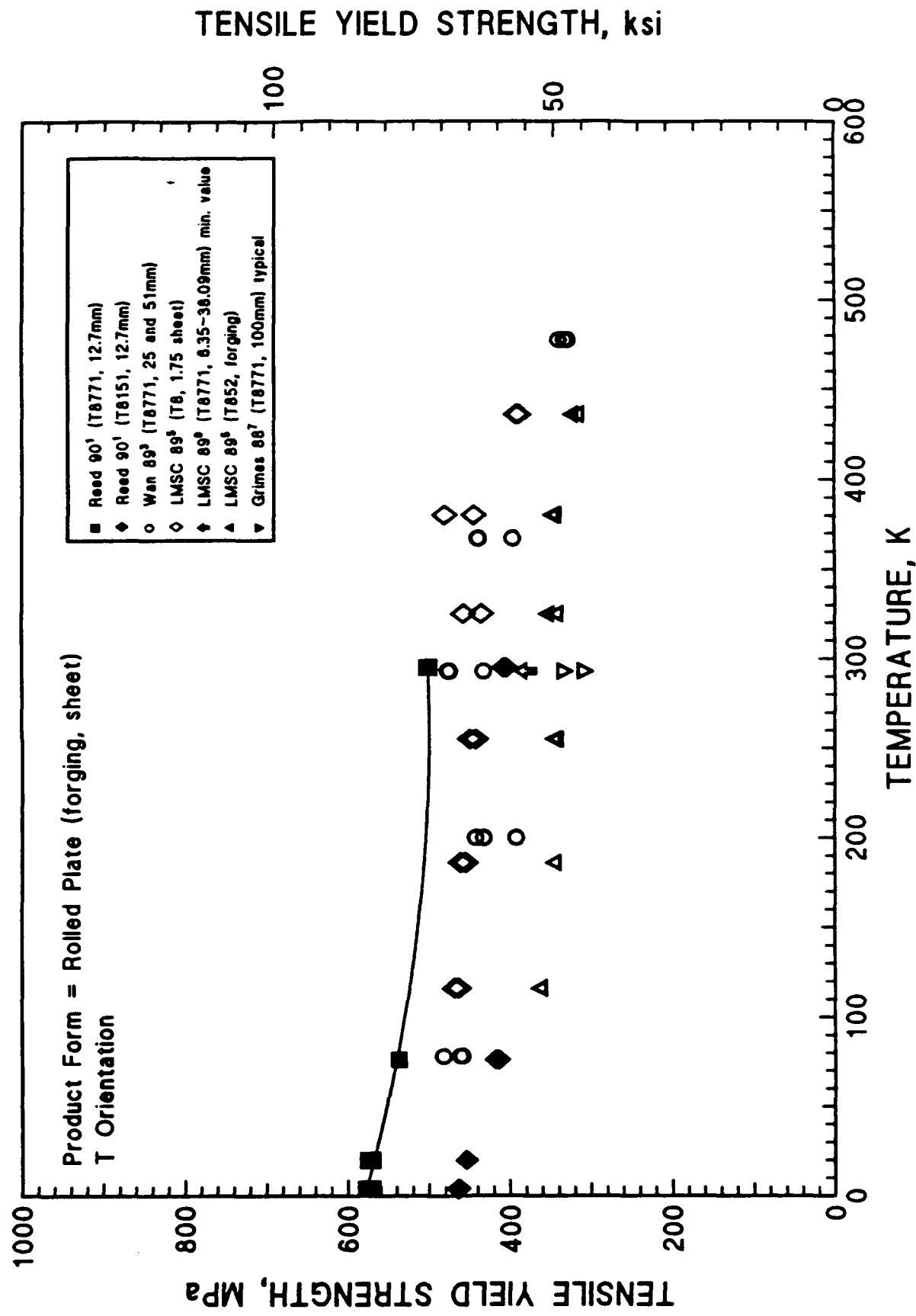
- Reed 90° (T8771, 12.7mm)
- ◆ Reed 90° (T8151, 12.7mm)
- Wan 89° (T8771, 25 and 51mm)
- ▲ Ritchie 88° (T8X, 11-16mm)
- ◇ LMSC 88° (T8511, extrusion)
- Sterke 88° (T8X, 25mm)
- ▼ Grimes 88° (T8771, 100mm) typical



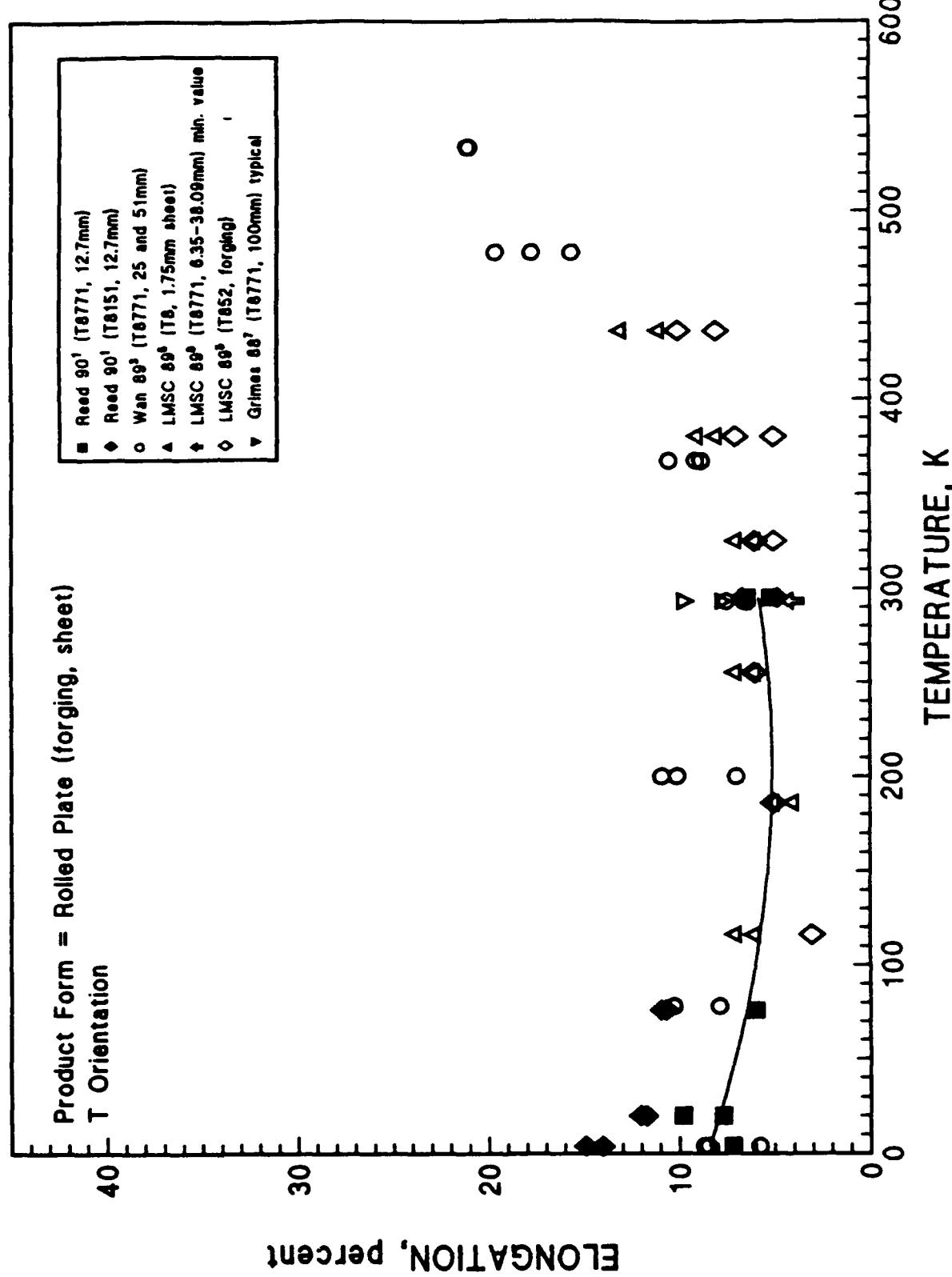
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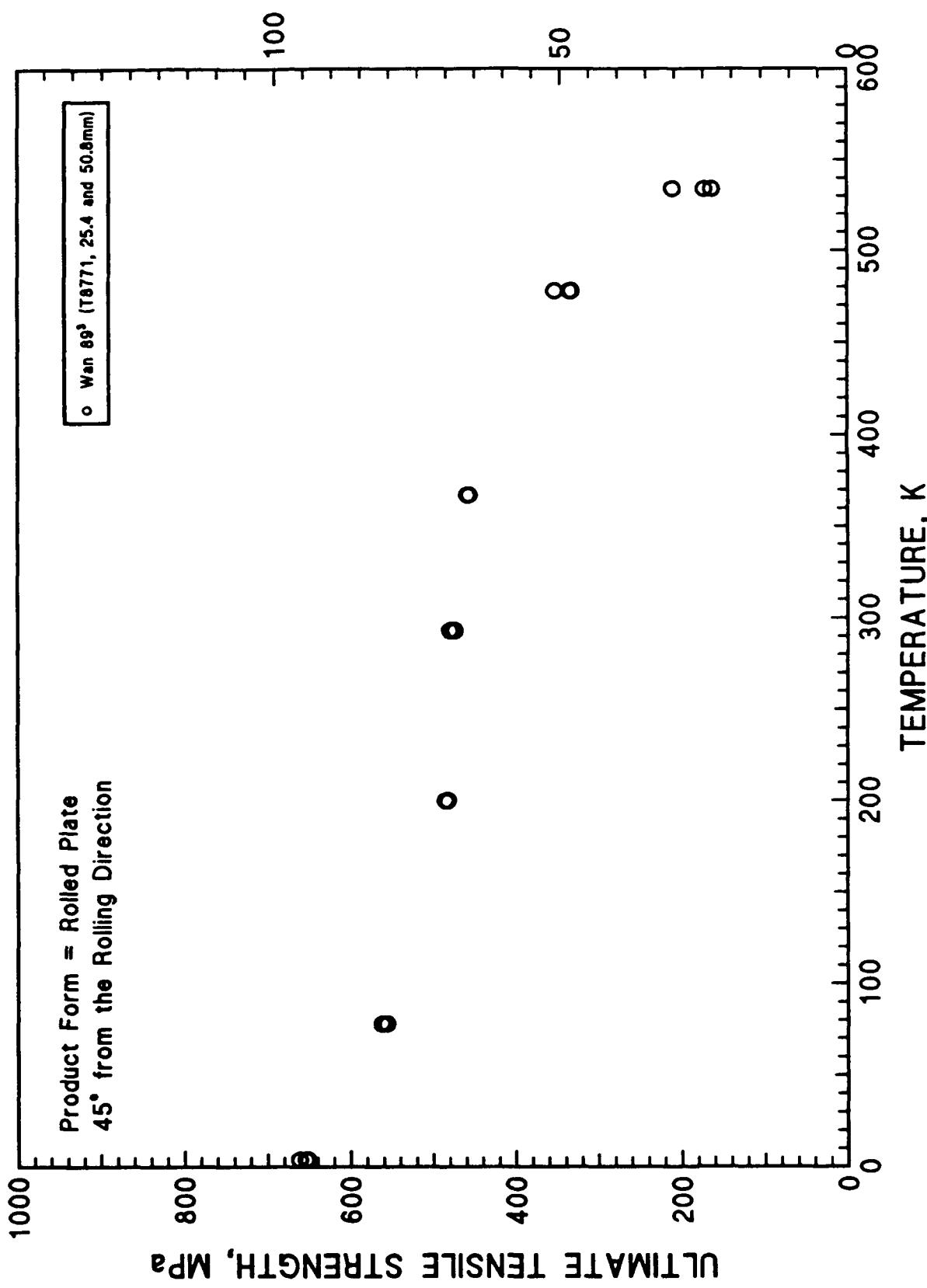


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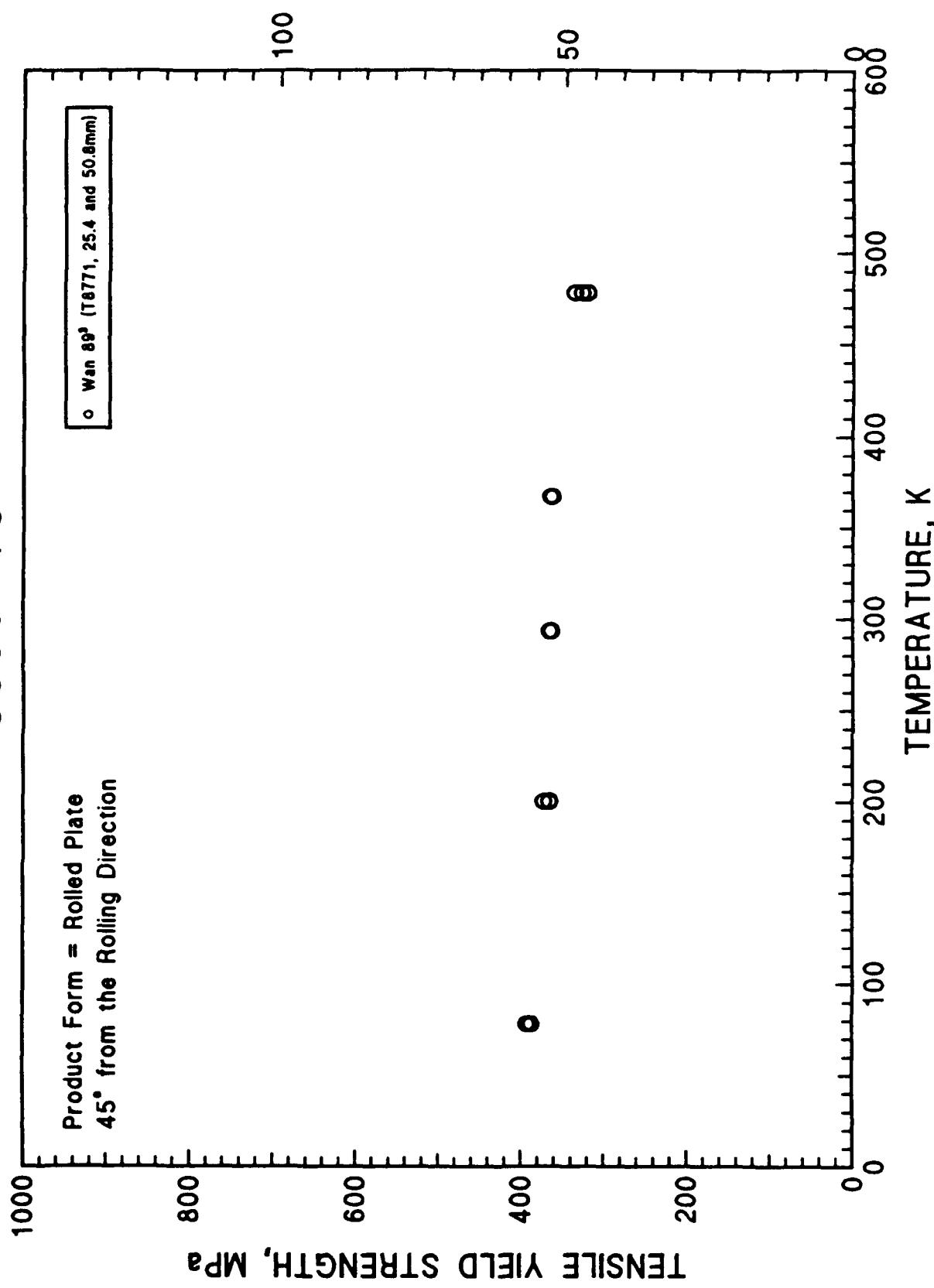
8090-T8

## ULTIMATE TENSILE STRENGTH, ksi



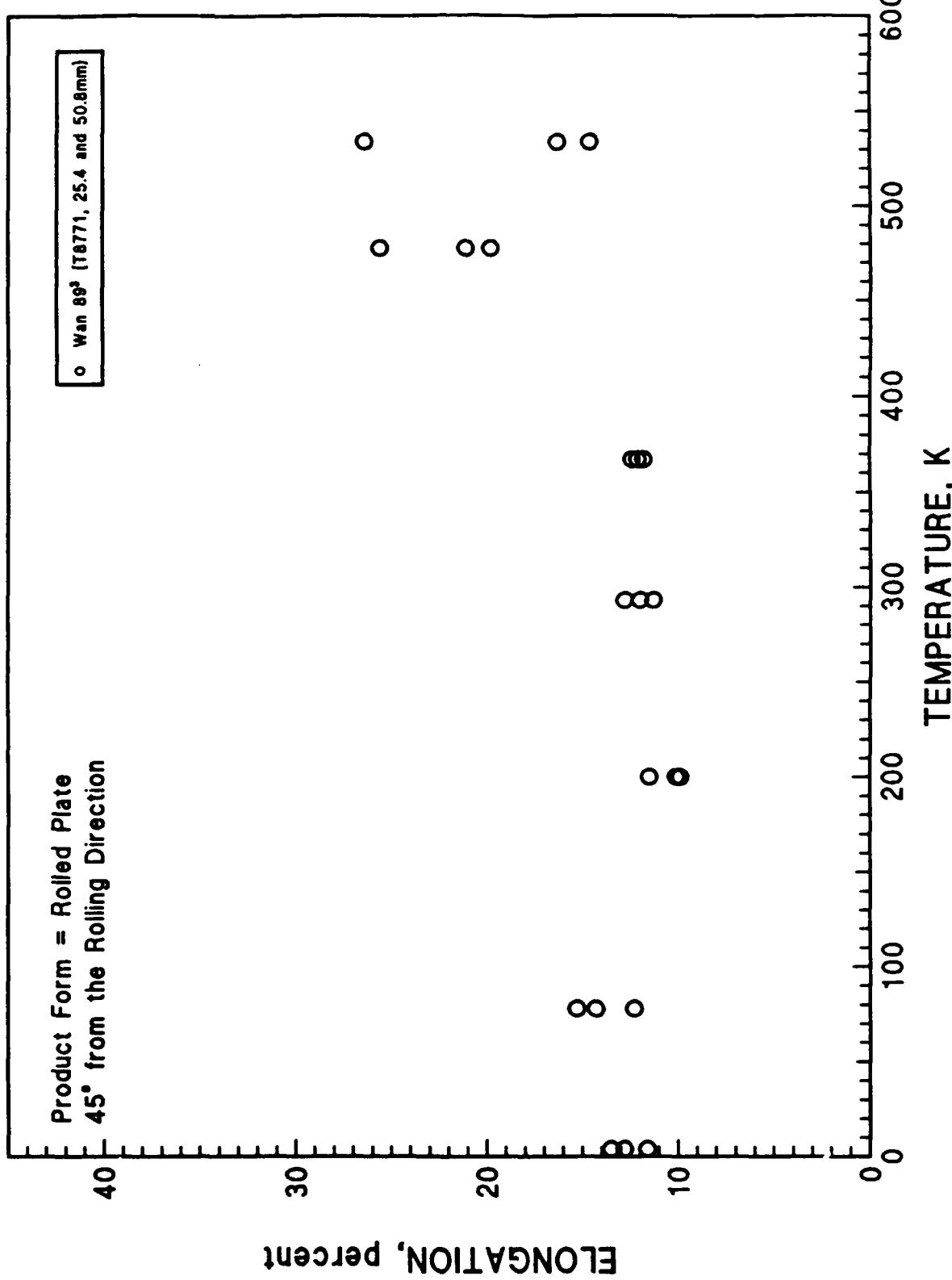
8090-T8

TENSILE YIELD STRENGTH, ksi



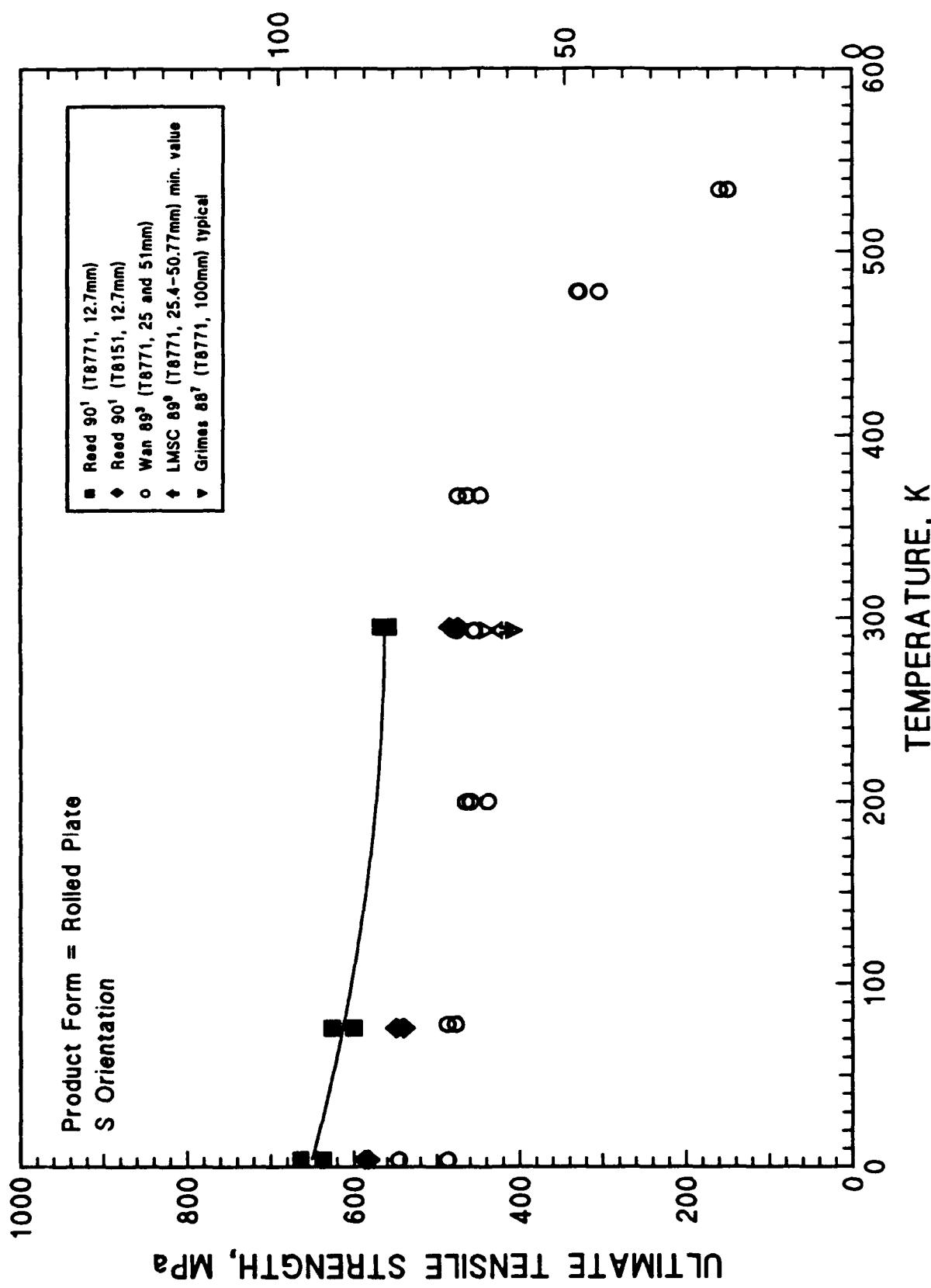
80090-T8

**Product Form = Rolled Plate  
45° from the Rolling Direction**

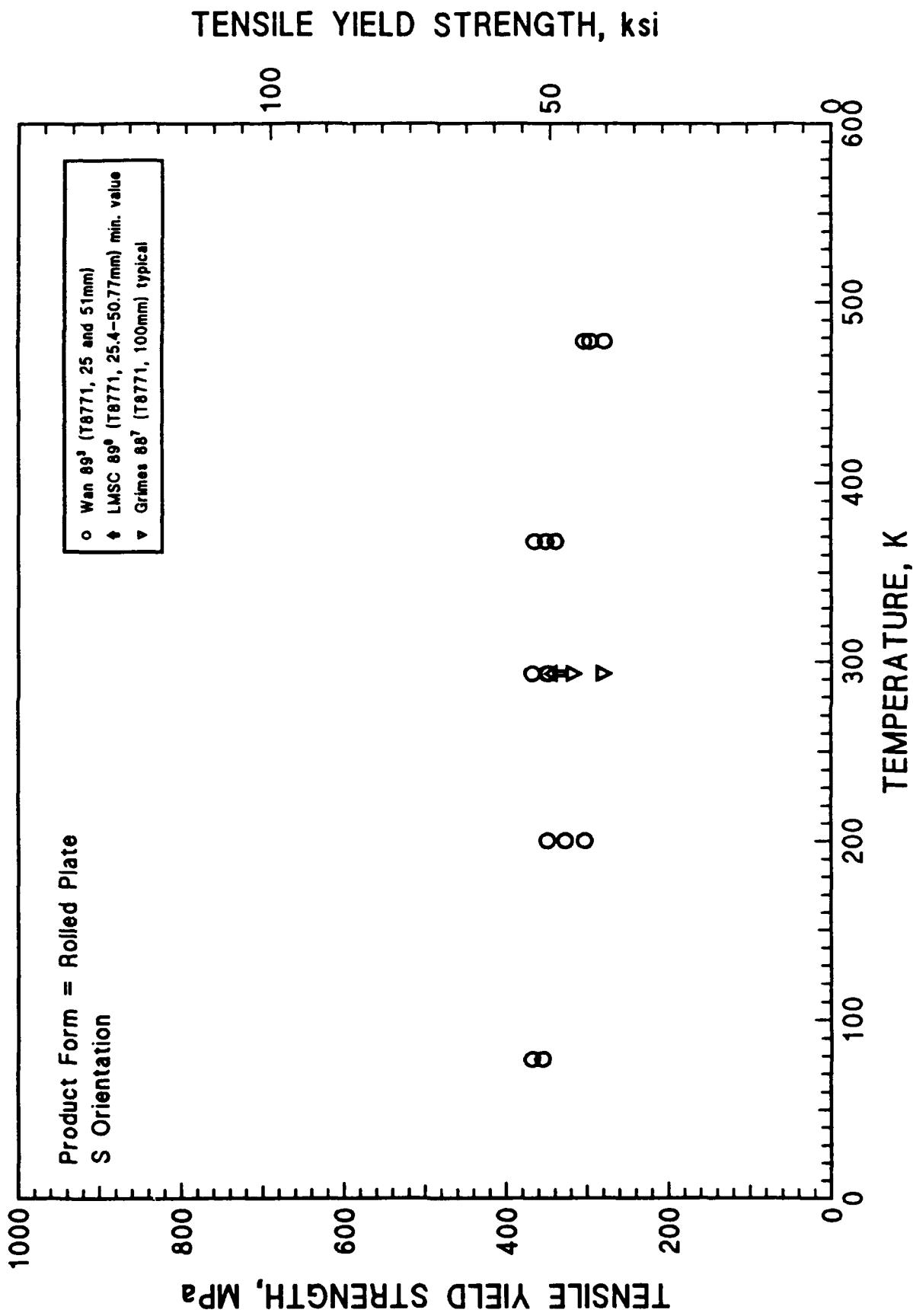


8090-T8

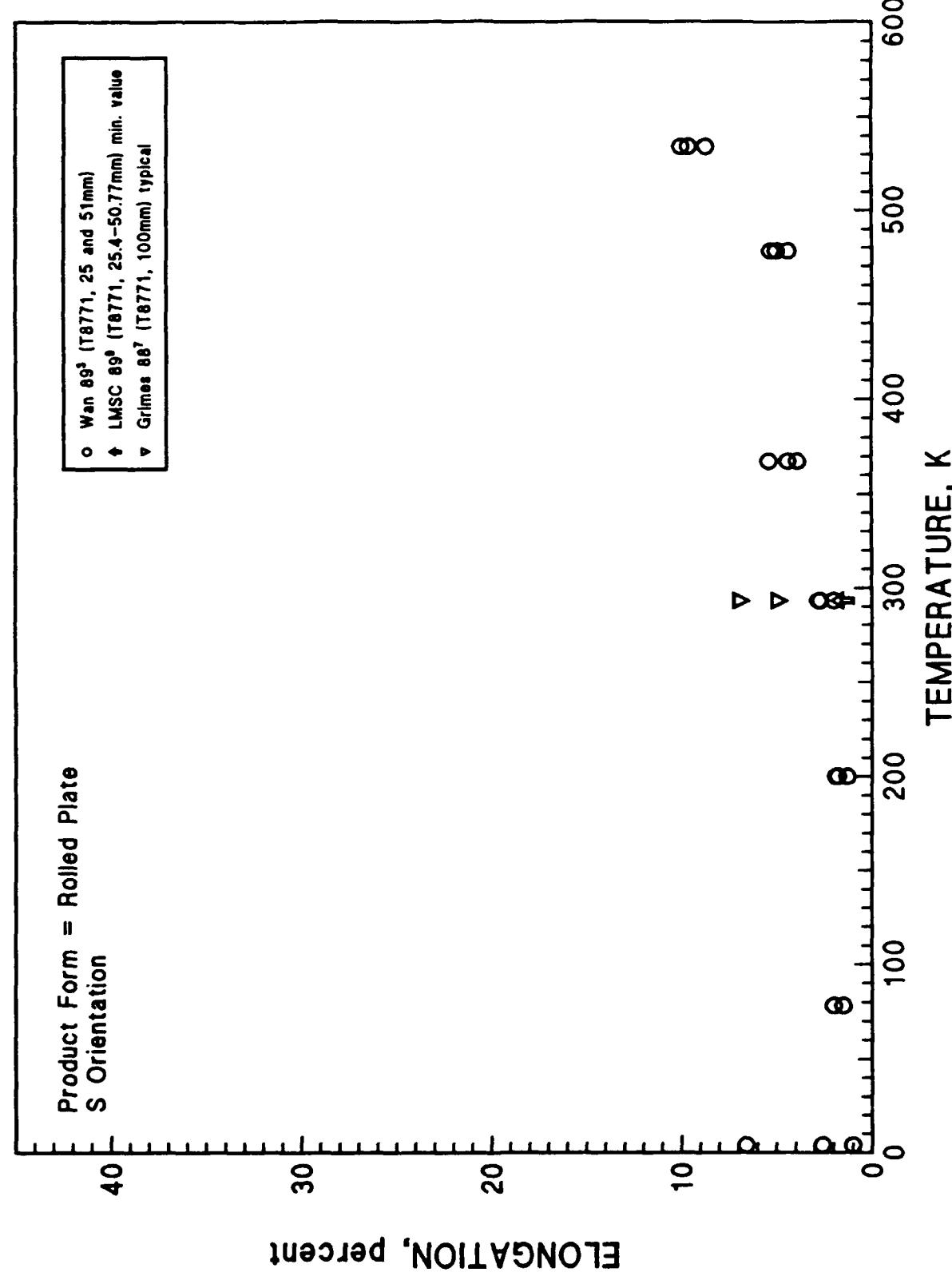
## ULTIMATE TENSILE STRENGTH, ksi

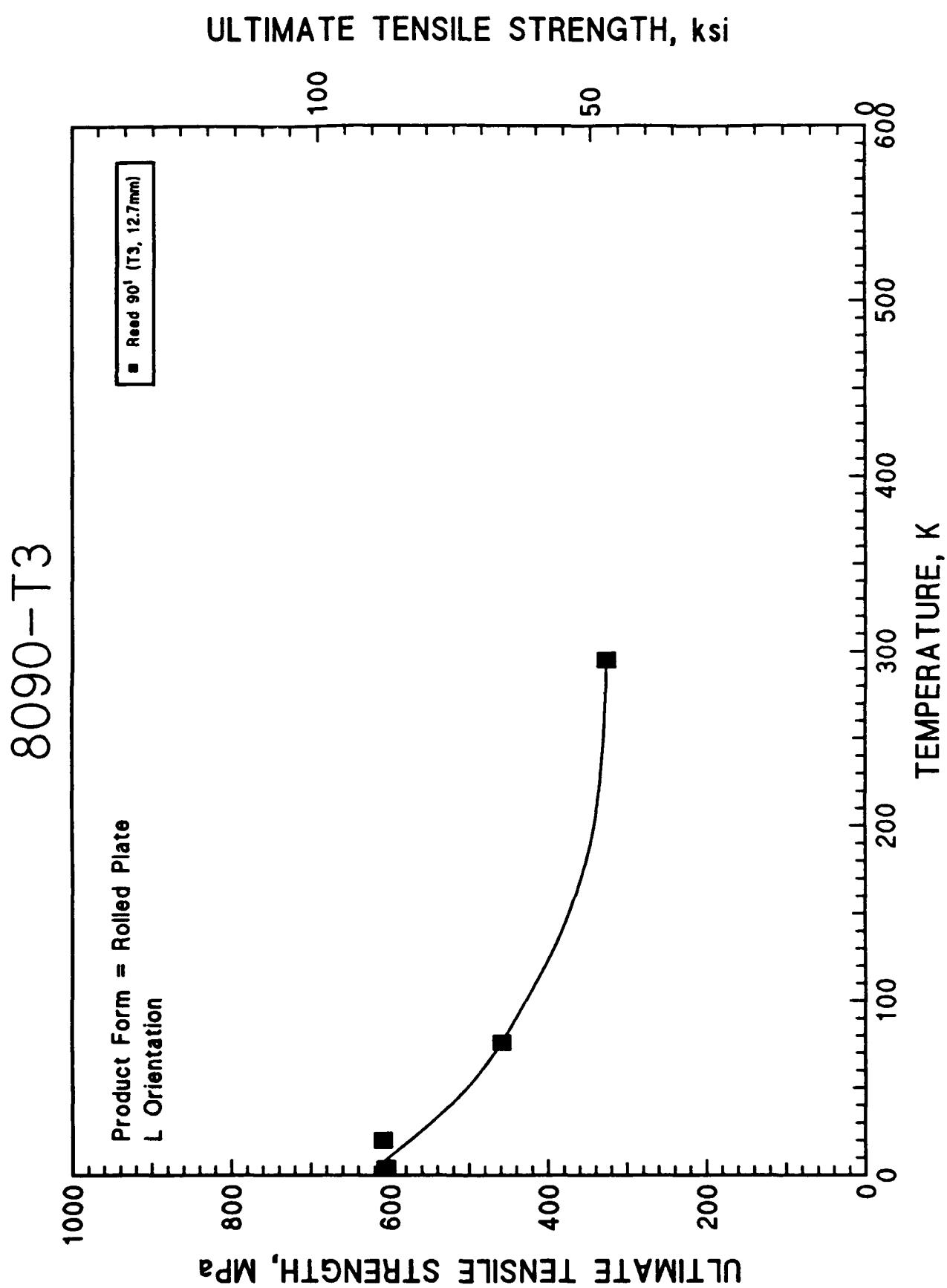


8090-T8

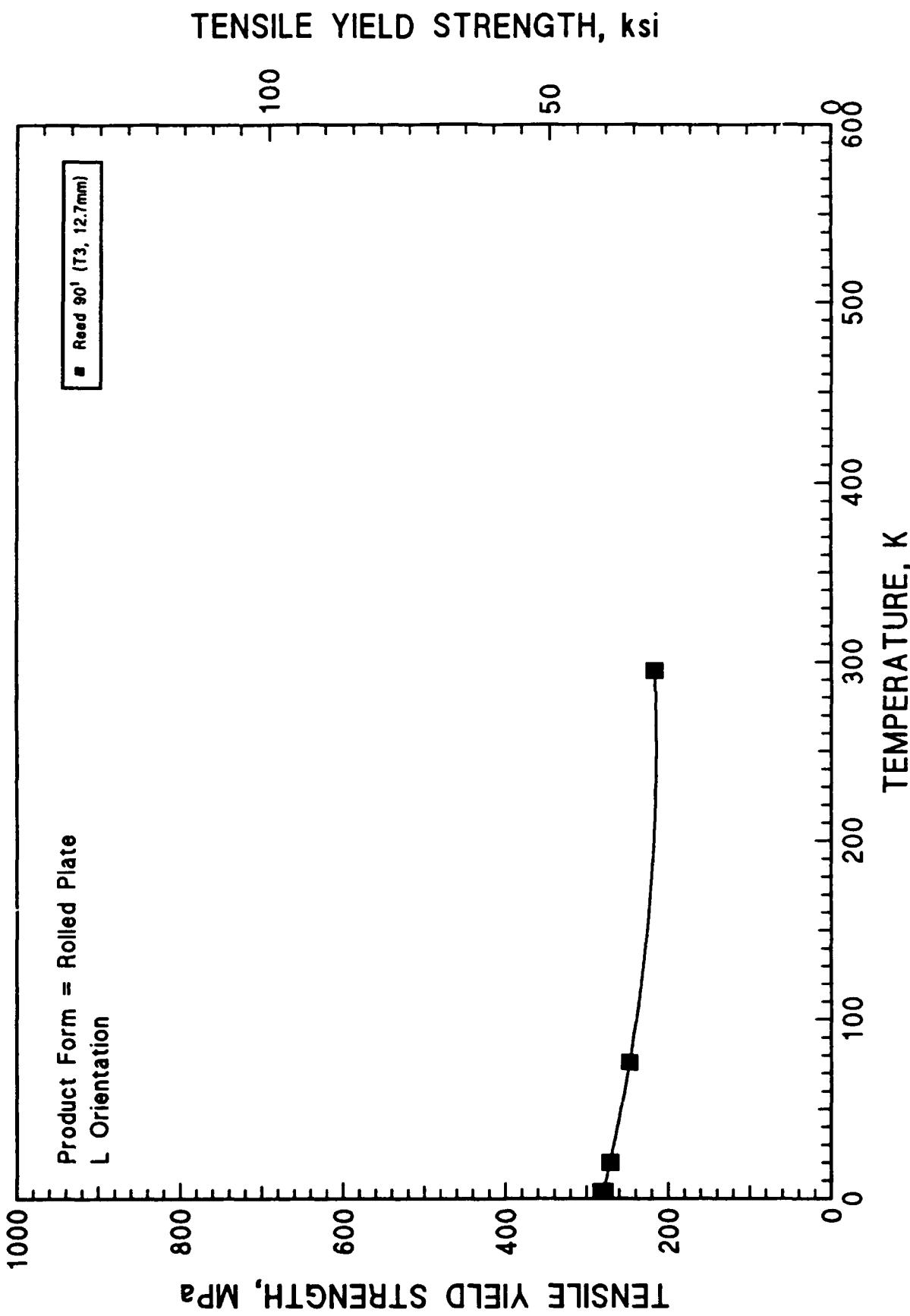


8090-T8





8090-T3



8090-T3

Product Form = Rolled Plate  
L Orientation

40

ELONGATION, percent

30

20

10

0

TEMPERATURE, K

600  
500  
400  
300  
200  
100  
0

■ Reed 90° (T3, 12.7mm)

35

25

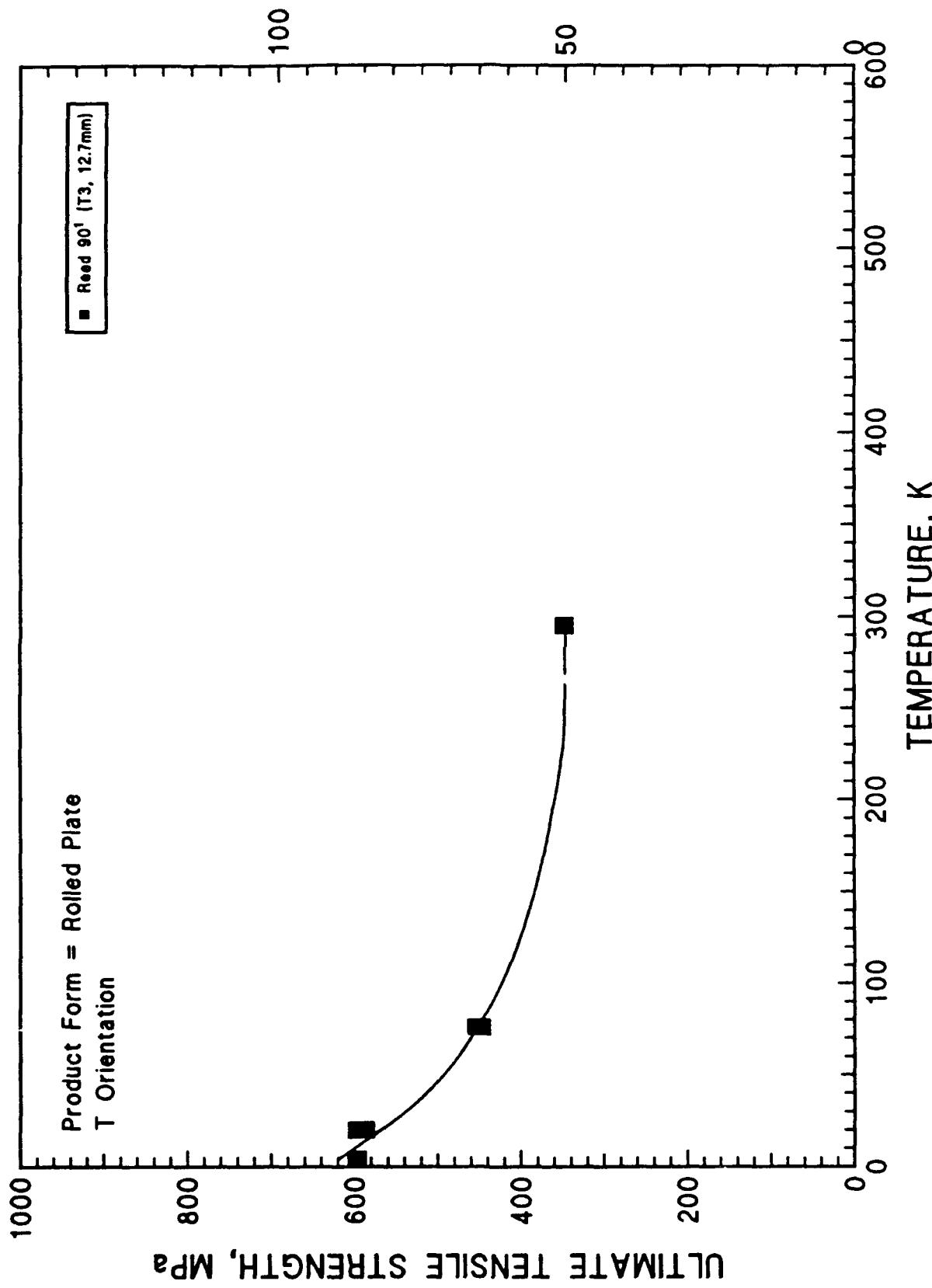
15

5

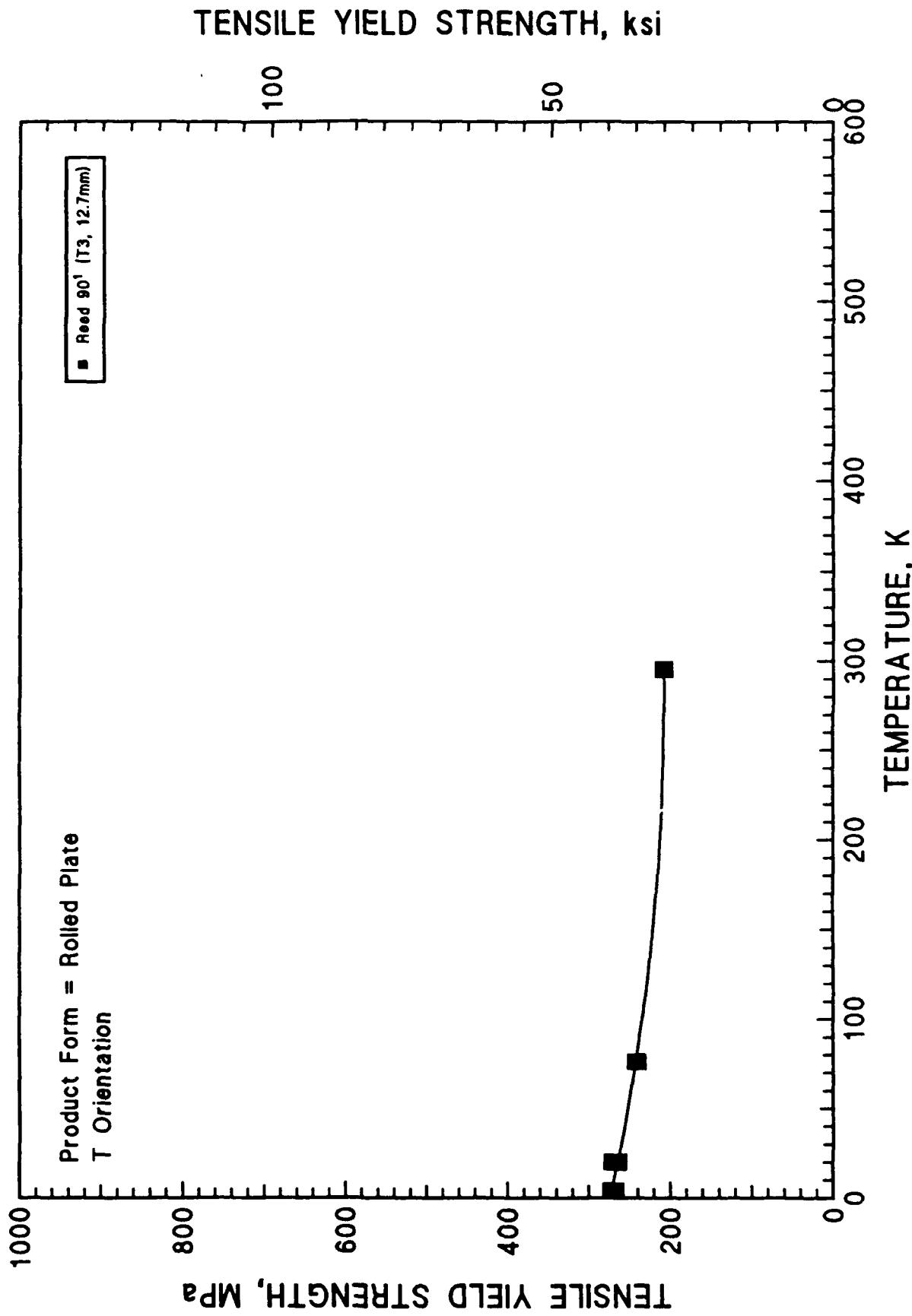
0

8090-T3

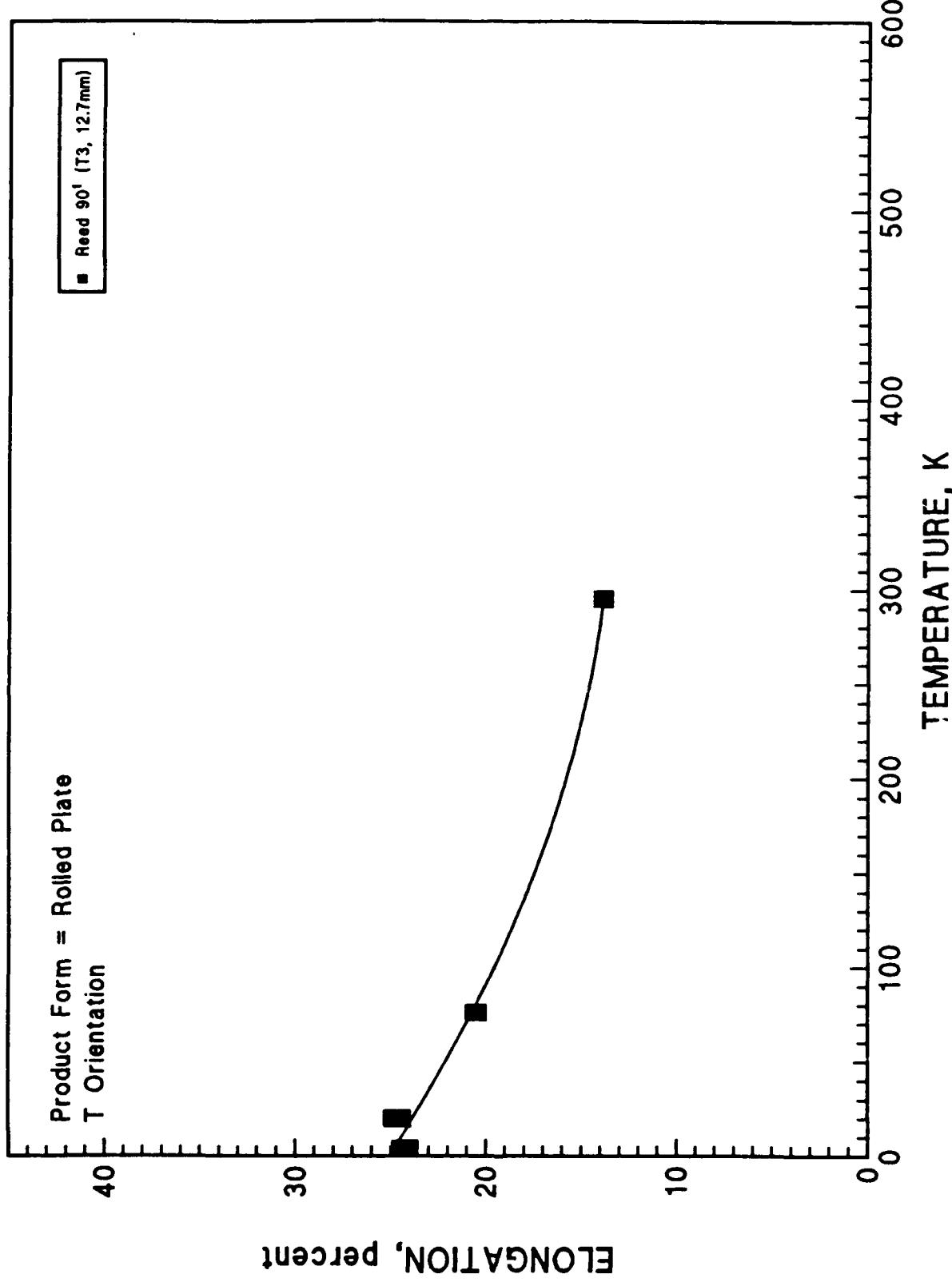
ULTIMATE TENSILE STRENGTH, ksi



8090-T3



8090-T3



## Al-Li ALLOY 8090

Ref & Note	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient.	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Soln. Temp. °C	Treat. Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
1A	295	567.	509.	4.1	6.4	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
1A	295	567.	514.	2.4	4.8	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
1A	76	701.	546.	11.4	11.	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
1A	76	697.	538.	NA	NA	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
1A	20	798.	570.	13.2	11.7	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
1A	20	799.	571.	14.2	14.1	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
1A	4	802.	569.	12.6	13.2	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
1A	4	811.	578.	13.7	17.1	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	1
3A	533	161.	NA	19.	82.7	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	533	212.	NA	19.5	81.9	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	478	340.	338.	19.3	51.4	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	478	336.	333.	16.4	61.7	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	478	346.	338.	17.5	58.6	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	367	507.	476.	7.7	10.2	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	367	497.	439.	7.6	11.1	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	293	503.	448.	6.	9.4	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1
3A	293	513.	445.	7.9	6.5	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch Temp. °C	Quench Cond.	Grain Size μm	Soln. Treat. Hardness	No. of Tests/ Data Pt	
3A	293	515.	477.	7.2	9.4	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	200	526.	427.	8.4	11.8	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	200	532.	492.	8.1	9.2	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	200	518.	456.	5.8	13.1	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	78	635.	520.	8.5	3.2	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	78	604.	486.	7.9	127.	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	78	639.	516.	8.3	7.7	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	4	683.	NA	6.4	12.6	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	4	635.	NA	6.8	16.3	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
3A	4	641.	NA	8.7	18.3	L	T8771	Rolled Plate	25.4-50.8	179	96. 4-6	545	0.5	HQ	NA	1
7A	293	440.	361.	8.5	MA	L	T8771	Rolled Plate	100	170	16. NA	NA	NA	NA	*	
7B	293	455.	397.	5.	MA	L	T8771	Rolled Plate	100	170	16. NA	NA	NA	NA	*	
5A	436	408.	397.	16.	MA	L	T8511	Extrusion	6.35	149	96. 3.5-4.0	545	1.	HQ	NA	1
5A	436	402.	390.	13.	MA	L	T8511	Extrusion	6.35	149	96. 3.5-4.0	545	1.	HQ	NA	1
5A	380	459.	398.	10.	MA	L	T8511	Extrusion	6.35	149	96. 3.5-4.0	545	1.	HQ	NA	1
5A	380	459.	403.	9.	MA	L	T8511	Extrusion	6.35	149	96. 3.5-4.0	545	1.	HQ	NA	1
5A	325	511.	427.	6.	MA	L	T8511	Extrusion	6.35	149	96. 3.5-4.0	545	1.	HQ	NA	1
5A	325	521.	434.	5.	MA	L	T8511	Extrusion	6.35	149	96. 3.5-4.0	545	1.	HQ	NA	1
5A	255	513.	412.	7.	MA	L	T8511	Extrusion	6.35	149	96. 3.5-4.0	545	1.	HQ	NA	1

\*See Comments

Ref. No.	Temp. K	F.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient.	Temper	Product Form	Thickness mm	Aging Temp. °C	Stretch h	Soln. Temp. °C	Aging Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt.
5A	255	524.	427.	7.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	WQ	NA	NA
5A	186	469.	392.	8.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	WQ	NA	NA
5A	186	487.	393.	9.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	WQ	NA	NA
5A	116	523.	396.	10.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	WQ	NA	NA
5A	116	550.	414.	11.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	WQ	NA	NA
1C	205	473.	401.	4.9	3.6	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1C	295	475.	403.	4.2	4.5	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1C	76	633.	411.	8.4	0.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1C	76	633.	412.	11.	7.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1C	20	720.	445.	10.4	5.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1C	20	778.	454.	14.8	12.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1C	4	767.	452.	16.7	14.1	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1C	4	771.	452.	14.1	13.1	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
4A	298	534.	462.	8.	NA	L	T8X	Rolled Plate	11-16	190	16.	3	NA	NA	NA	L:1500; T:350; S:40	NA
6A	300	456.	367.	9.4	NA	L	T8X	Rolled Plate	25	190	4.	2-2.5	NA	NA	NA	NA	1
6A	300	464.	406.	9.4	NA	L	T8X	Rolled Plate	25	190	6.	2-2.5	NA	NA	NA	NA	1
6A	77	542.	392.	16.	NA	L	T8X	Rolled Plate	25	190	4.	2-2.5	NA	NA	NA	NA	1
6A	77	566.	411.	16.	NA	L	T8X	Rolled Plate	25	190	6.	2-2.5	NA	NA	NA	NA	1
8A	195	495.	450.	6.	NA	L	T651	Rolled Plate	6.35-38.1	NA	NA	NA	NA	NA	NA	NA	*

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. L	Temper T3	Product Form	Thickness mm	Product Temp. °C	Time h	Stretch %	Quench Cond.	Soln. Treat. Time	Grain Size μm	Hardness	No. of Tests/ Date Pt	
1E 297	328.	216.	11.7	16.7	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1	
1E 297	328.	216.	13.1	17.4	L	T3	Rolled Plate	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1	
1E 76	457.	248.	19.6	29.8	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 76	480.	248.	23.4	24.7	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 20	610.	270.	28.1	26.5	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 20	607.	272.	27.	24.3	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 4	604.	278.	26.8	30.	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 4	606.	203.	26.3	27.5	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1
1A 295	567.	499.	5.2	11.	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A 295	566.	502.	6.4	12.6	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A 76	682.	NA	NA	NA	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A 76	670.	537.	6.	5.6	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A 20	772.	570.	9.8	9.5	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A 20	768.	575.	7.7	7.2	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A 4	784.	578.	NA	NA	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A 4	768.	570.	7.2	7.2	T	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
3A 534	182.	NA	21.	74.8	T	T6771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	WQ	NA	NA	1	
3A 534	196.	NA	21.1	70.7	T	T6771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1	
3A 470	331.	328.	15.6	53.1	T	T6771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1	

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper Form	Product Form	Thickness mm	Temp. °C	Time h	Stretch Z	Soln. Temp. °C	Treat. h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt.
3A 476 341. 339. 17.7 54.0 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 476 334. 332. 19.6 59.6 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 367 492. 436. 9.1 14.6 T 76771 Rolled Plate 25.4-50.0 176 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 367 496. 439. 8.8 14. T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 367 471. 396. 10.5 26.6 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 293 513. 476. 7.5 6.7 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 293 483. 432. 6.4 11.2 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 293 510. 474. 6.6 5.1 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 200 530. 432. 10.9 6.4 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 200 532. 442. 10.1 7.6 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 200 496. 392. 7. 5.5 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 78 622. 461. 10.3 7.3 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 78 620. 459. 10.3 7.2 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 78 598. 482. 7.9 12.7 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 4 670. MA 8.5 16.5 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
3A 4 628. MA 8.7 17.8 T 76771 Rolled Plate 25.4-50.0 179 96. 4-6 545 0.5 HQ NA NA NA 1																		
7C 293 430. 310. 9.8 MA T 76771 Rolled Plate 100 NA NA NA NA NA NA NA NA NA 1																		
7D 293 437. 335. 7.8 MA T 76771 Rolled Plate 100 NA NA NA NA NA NA NA NA NA 1																		

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Quench Temp. °C	Quench Cond. h	Soln. Treat. NA	Grain Size μm	Hardness NA	Tests/ Data Pt.
SA	293	448.	379.	4.	NA	T	T8771	Rolled Plate	6.35-38.1	NA	NA	NA	NA	NA	NA	NA	*
SC	436	306.	314.	0.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	436	305.	321.	10.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	380	434.	345.	5.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	380	450.	342.	7.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	325	463.	340.	5.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	325	458.	351.	6.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	255	465.	340.	6.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	255	464.	343.	6.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	186	461.	343.	5.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	186	468.	343.	5.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	116	473.	361.	3.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
SC	116	473.	360.	3.	NA	T	T852	Forgings	254	149	96.	4*	545	1.	HQ	NA	NA
IC	295	507.	403.	6.6	7.1	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA
IC	295	508.	407.	4.8	5.9	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA
IC	76	642.	413.	10.9	10.5	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA
IC	76	643.	417.	10.7	10.	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA
IC	20	752.	453.	12.	9.5	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA
IC	20	760.	453.	11.7	11.4	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. T	Temper T8151	Product Form	Thickness mm	Temp. °C	Time h	Stretch Cond.	Soln. Temp. °C	Time h	Quench	Grain Size μm	Hardness	Tests/ Date Pt	No. of
1C 4	776.	462.	14.	14.7	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1C 4	763.	464.	14.9	14.3	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
5B 436	416.	391.	11.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 436	407.	388.	13.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 360	494.	479.	9.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 360	499.	443.	8.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 325	534.	456.	7.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 325	514.	434.	6.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 255	532.	446.	6.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 255	526.	441.	7.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 186	535.	460.	4.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 186	532.	454.	5.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 116	582.	468.	6.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
5B 116	581.	463.	7.	NA	T	T8	Sheet	1.76	149	96.	2.5-3.0	545	1.	HQ	NA	NA	NA	NA	1
6A 295	480.	420.	7.	NA	T	T851	Rolled Plate	25-40	190	6.	0	NA	NA	NA	NA	NA	NA	*	
1E 297	347.	209.	13.0	24.5	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	NA	116.5	1
1E 297	349.	207.	13.0	28.0	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	NA	116.5	1
1E 76	454.	240.	20.6	37.3	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	NA	116.5	1
1E 76	447.	243.	20.4	36.9	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	NA	116.5	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. T	Temper T3	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Soln. Temp. °C	Treat. h	Quench Cond.	Grain Size μm	Hardness	Tests/ Data Pt.	
1E	20	598.	264.	24.9	29.2	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1
1E	20	596.	271.	24.4	26.1	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1
1E	4	596.	273.	24.	29.7	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1
1E	4	599.	267.	26.5	28.5	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1
10A	293	302.	142.	23.	40.	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	273	263.	140.	25.5	50.1	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	258	271.	140.	25.	59.5	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	238	262.	142.	24.5	57.8	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	218	250.	140.	26.5	65.6	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	198	254.	142.	27.5	68.5	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	173	257.	146.	30.	66.7	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	153	257.	150.	30.	63.	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
10A	78	352.	167.	41.5	49.9	T	0	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	NA	1
3A	534	163.	NA	14.6	84.8	45*	T8771	Rolled Plate	25.4-50.6	179	96.	4-6	54.5	0.5	HQ	NA	NA	1	
3A	534	172.	NA	16.3	85.1	45*	T8771	Rolled Plate	25.4-50.6	179	96.	4-6	54.5	0.5	HQ	NA	NA	1	
3A	478	332.	319.	26.4	77.	45*	T8771	Rolled Plate	25.4-50.6	179	96.	4-6	54.5	0.5	HQ	NA	NA	1	
3A	478	352.	335.	25.6	58.5	45*	T8771	Rolled Plate	25.4-50.6	179	96.	4-6	54.5	0.5	HQ	NA	NA	1	
3A	478	334.	326.	19.8	64.7	45*	T8771	Rolled Plate	25.4-50.6	179	96.	4-6	54.5	0.5	HQ	NA	NA	1	

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper Form	Product Thickness mm	Product Form	Aging Temp. °C	Time h	Stretch Z	Temp. °C	Time h	Quench Cond.	Grain Size μm	Solv. Treat.	Hardness	No. of Tests/ Date Pt.
3A	367	458.	363.	12.4	27.9	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	NA	1
3A	367	457.	364.	11.6	26.5	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	367	456.	362.	12.1	29.7	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	293	476.	365.	11.3	16.9	45*	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	293	473.	363.	12.	12.4	45*	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	293	479.	364.	12.6	20.	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	200	485.	372.	11.5	12.5	45*	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	200	482.	365.	9.9	13.7	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	200	485.	365.	10.1	11.1	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	78	559.	392.	14.3	11.4	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	78	562.	387.	15.3	18.4	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	78	556.	387.	12.3	11.2	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	4	662.	NA	12.6	19.4	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	4	654.	NA	13.5	19.4	45*	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3A	4	632.	NA	11.6	19.4	45*	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	WQ	NA	NA	NA	1
1B	295	558.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	295	567.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	76	626.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	76	600.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments.

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper HA	Product Form	Thickness mm	Product Temp. °C	Aging Time h	Aging Temp. °C	Stretch Z	Quench Temp. °C	Time h	Soln. Treat. Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt.
1B	4	664.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	4	637.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
3B	534	159.	NA	8.7	36.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	534	149.	NA	9.6	31.5	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	534	159.	NA	10.	23.1	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	478	304.	270.	5.3	22.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	478	326.	296.	5.	24.6	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	478	330.	304.	4.4	15.8	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	367	447.	339.	5.4	13.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	367	474.	365.	4.4	3.6	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	367	463.	351.	3.9	12.2	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	293	456.	350.	2.7	11.3	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	293	476.	368.	2.	8.4	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	293	454.	348.	2.8	11.9	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	200	459.	348.	1.9	12.3	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	200	436.	327.	1.3	11.8	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	200	465.	303.	1.6	14.5	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	78	487.	368.	1.5	6.	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1
3B	78	477.	355.	2.	9.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. I	Temper Form	Product Thickness mm	Stretch Temp. °C	Time h	$\chi$	Soln. Treat. Temp. °C	Quench Cond. h	Grain Size $\mu\text{m}$	Hardness	No. of Tests/ Data Pt.
3B	4	487.	NA	1.	1.	S	T8771	Rolled Plate	25.4-30.6	178	96.	4-6	545	0.5	NA	NA
3B	4	546.	NA	2.6	1.2	S	T8771	Rolled Plate	25.4-30.6	179	96.	4-6	545	0.5	NA	NA
3B	4	546.	NA	0.6	2.1	S	T8771	Rolled Plate	25.4-30.6	179	96.	4-6	545	0.5	NA	NA
7E	293	442.	320.	7.	NA	S	T8771	Rolled Plate	100	NA	NA	NA	NA	NA	NA	*
7F	293	410.	263.	5.	NA	S	T8771	Rolled Plate	100	NA	NA	NA	NA	NA	NA	*
9B	293	421.	338.	1.5	NA	S	T8771	Rolled Plate	25.4-30.6	NA	NA	NA	NA	NA	NA	*
1D	295	483.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
1D	295	473.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
31	1D	76	546.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA
1D	76	539.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
1D	4	582.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
1D	4	586.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
8B	293	435.	365.	2.	NA	S	T651	Rolled Plate	25-40	NA	NA	NA	NA	NA	NA	*

\*See Comments

Comments from the Al-Li Alloy 8090 Data Table

Reference and  
Note Number

3A-B--Temper T851 appears to be T8771, and is reported here as such.

5C--Cold work is in compression.

8A--Values reported are "typical" properties.

9A--Values reported are "minimum" properties.

**TEST PARAMETERS**  
Al-Li ALLOY 6090

Ref & Note No.	Strain Rate 10^-4/s	Specimen Type	Diam mm	Thick mm	G.L. mm	Specimen Location	Expo min	Supplier Prod.	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements wt%				Minor Elements wt%			
												Li	Cu	Mg	Zr	Si	Fe	As	
1A	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcan	1969	3503302A	1.635 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	
1B	2.2	Round	2.5	NA	25.4	Random	5.	Alcan	1969	3503302A	1.635 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	
1C	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcan	1969	35712859	1.533 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	
1D	2.2	Round	2.5	NA	25.4	Random	5.	Alcan	1969	35712859	1.533 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	
1E	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcan	1969	3518302A	0.254 X 0.254	2.34	1.2	0.6	0.12	0.03	0.05	NA	
3A	8.3	Round	12.7	NA	50.8	NA	2.	Alcan	1987	NA	NA	2.4*	1.3	0.8	0.12	0.1	0.3	NA	
3B	8.3	Round	12.7	NA	50.8	NA	2.	Alcan	1987	NA	NA	2.4*	1.3	0.8	0.12	0.1	0.3	NA	
4A	8.3	Round	12.7	NA	50.8	NA	2.	Alcan	1987	NA	NA	2.4*	1.3	0.8	0.12	0.1	0.3	NA	
5A	0.63	NA	NA	NA	NA	Random	30.	Alcan	NA	NA	NA	0.46 X 0.25	2.5*	1.2	0.7	0.12	0.04	0.08	NA : 0.001
5C	0.63	NA	NA	NA	NA	Random	30.	Alcan	NA	NA	NA	0.46 X 0.25	2.5*	1.2	0.7	0.12	0.04	0.08	NA : 0.001
6A	1.0	Round	NA	NA	NA	NA	15.	Alcan	NA	NA	NA	2.28	0.9	0.9	0.13	0.06	0.13	NA	
5B	0.63	NA	NA	NA	NA	NA	30.	Alcan	NA	NA	NA	1.22 X 3.66	2.5*	1.2	0.7	0.12	0.04	0.08	NA : 0.001
7A	NA	NA	NA	NA	NA	to the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
7B	NA	NA	NA	NA	NA	to the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
7C	NA	NA	NA	NA	NA	to the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
7D	NA	NA	NA	NA	NA	to the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
7E	NA	NA	NA	NA	NA	to the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
7F	NA	NA	NA	NA	NA	to the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Ref & Note No.	Strain Rate	Type	Specimen			Specimen Location	Expo Time min	Supplier Prod	Yr. Prod	Lot No.	Product				Major Elements wt%				Minor Elements wt%				
			Diam	Thick	G.L.						Li	Cu	Mg	Zr	Si	Fe	As	Na	K	Ca	Al	Cr	Sn
8A	NA	NA	NA	NA	NA	NA	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	2.5*	1.3	0.7	0.12	0.1	0.2	NA	NA
8B	NA	NA	NA	NA	NA	NA	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	2.5*	1.3	0.7	0.12	0.1	0.2	NA	NA:0.001
9A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.5*	1.2	0.7	0.08	0.04	0.08	NA	NA:0.001
9B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.5*	1.2	0.7	0.09	0.04	0.08	NA	NA:0.001
10A	4.6	Round	5.	NA	36.	NA	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Comments from the Al-Li Alloy 8090 Test Parameter Table

Reference and  
Note Number

3A-B--Reported composition is based on typical values.

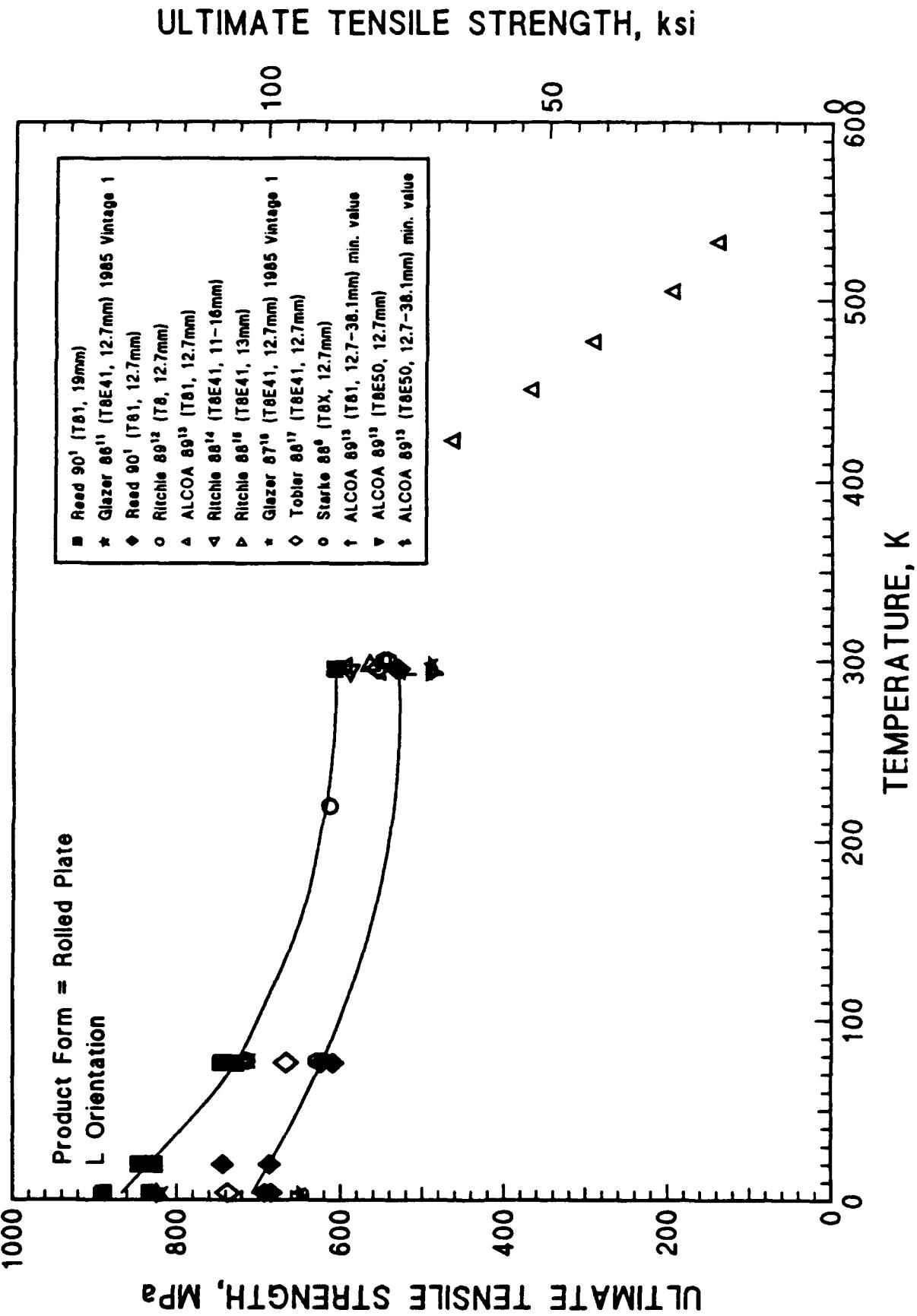
4A--Reported composition is based on nominal values.

5A-C--Reported composition is the average of the range provided for in the Lockheed requirements.

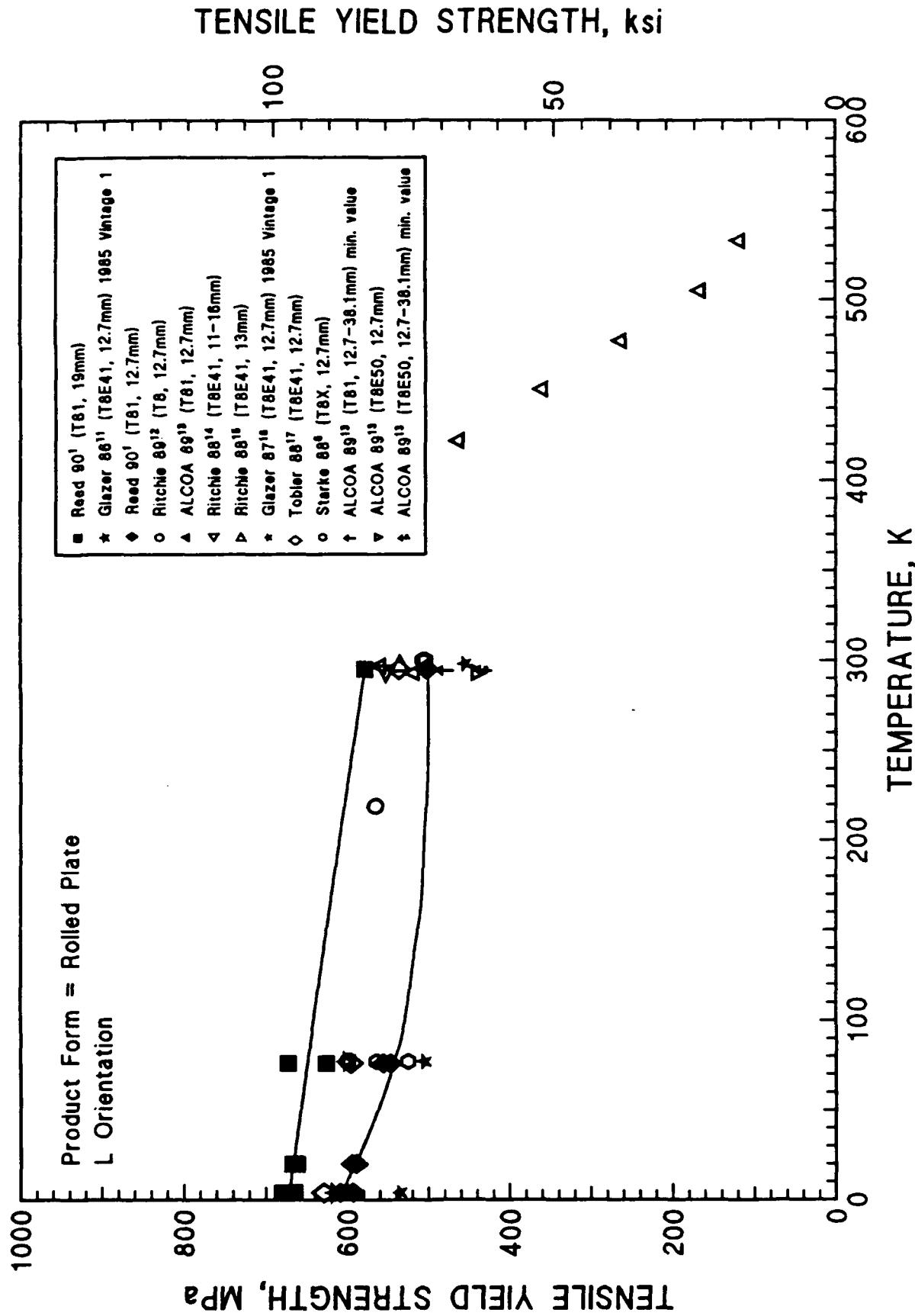
8A--Reported composition is based on nominal values.

9A-B--Reported composition is the average of the range provided for in the Lockheed requirements.

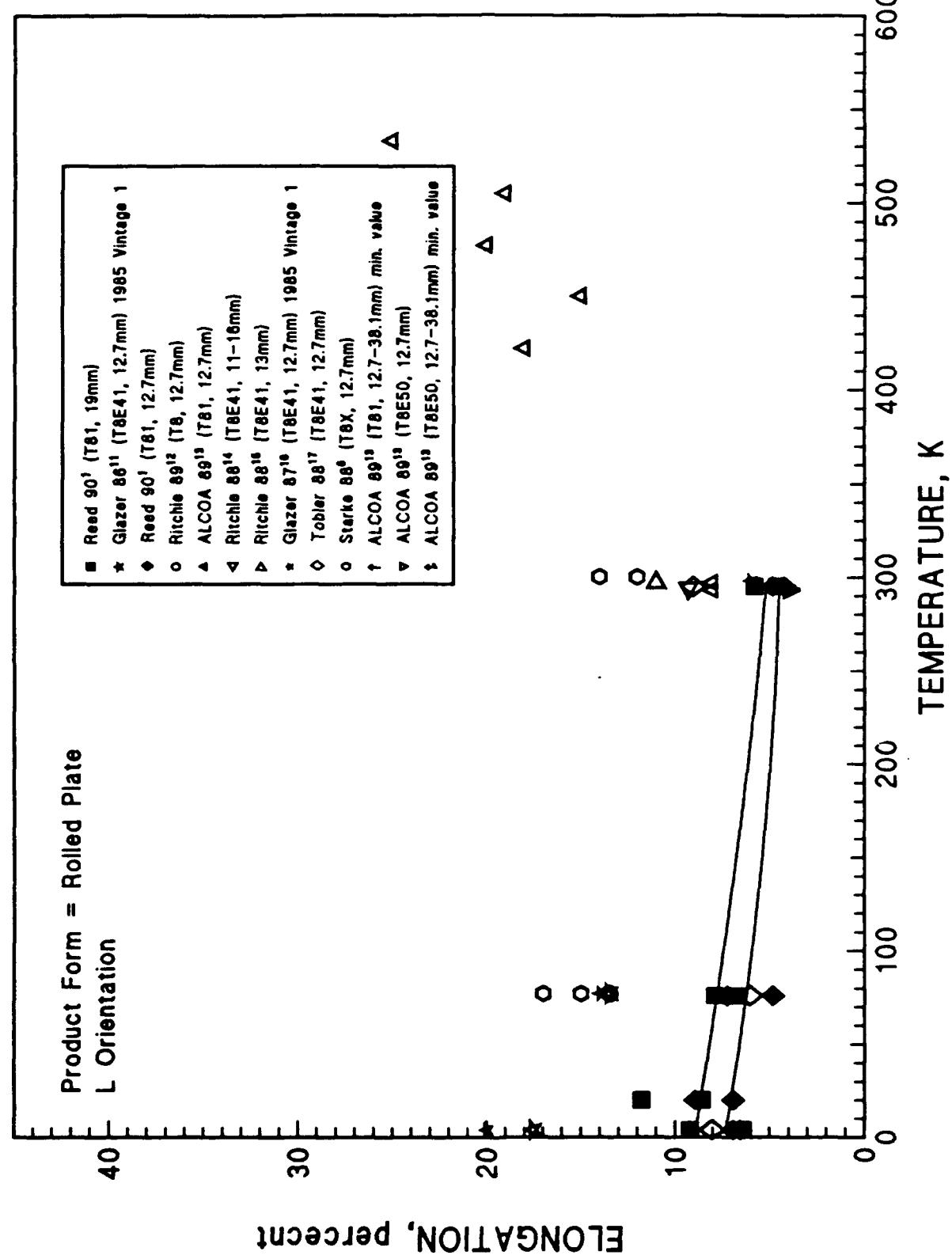
2090-T8



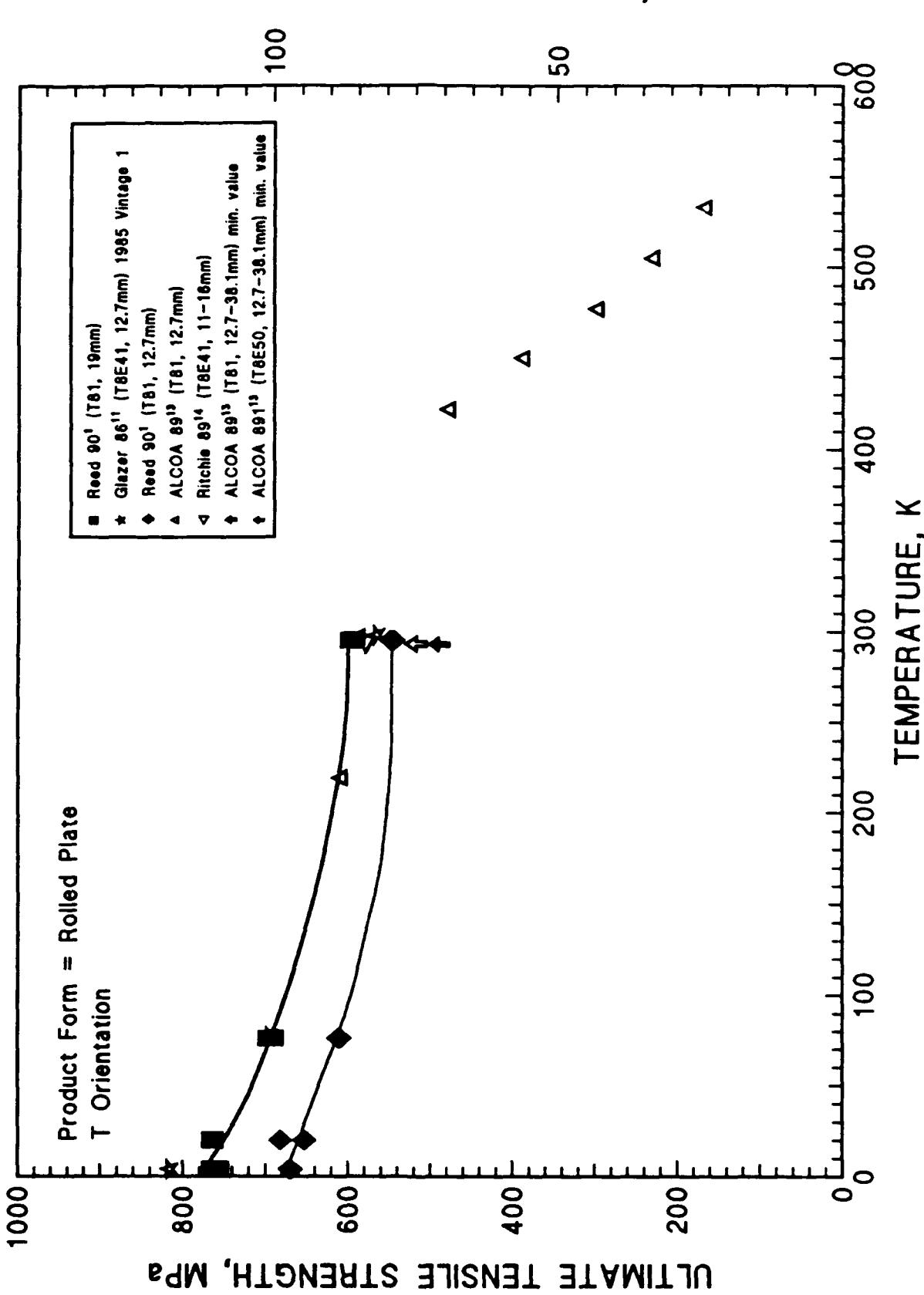
2090-T8



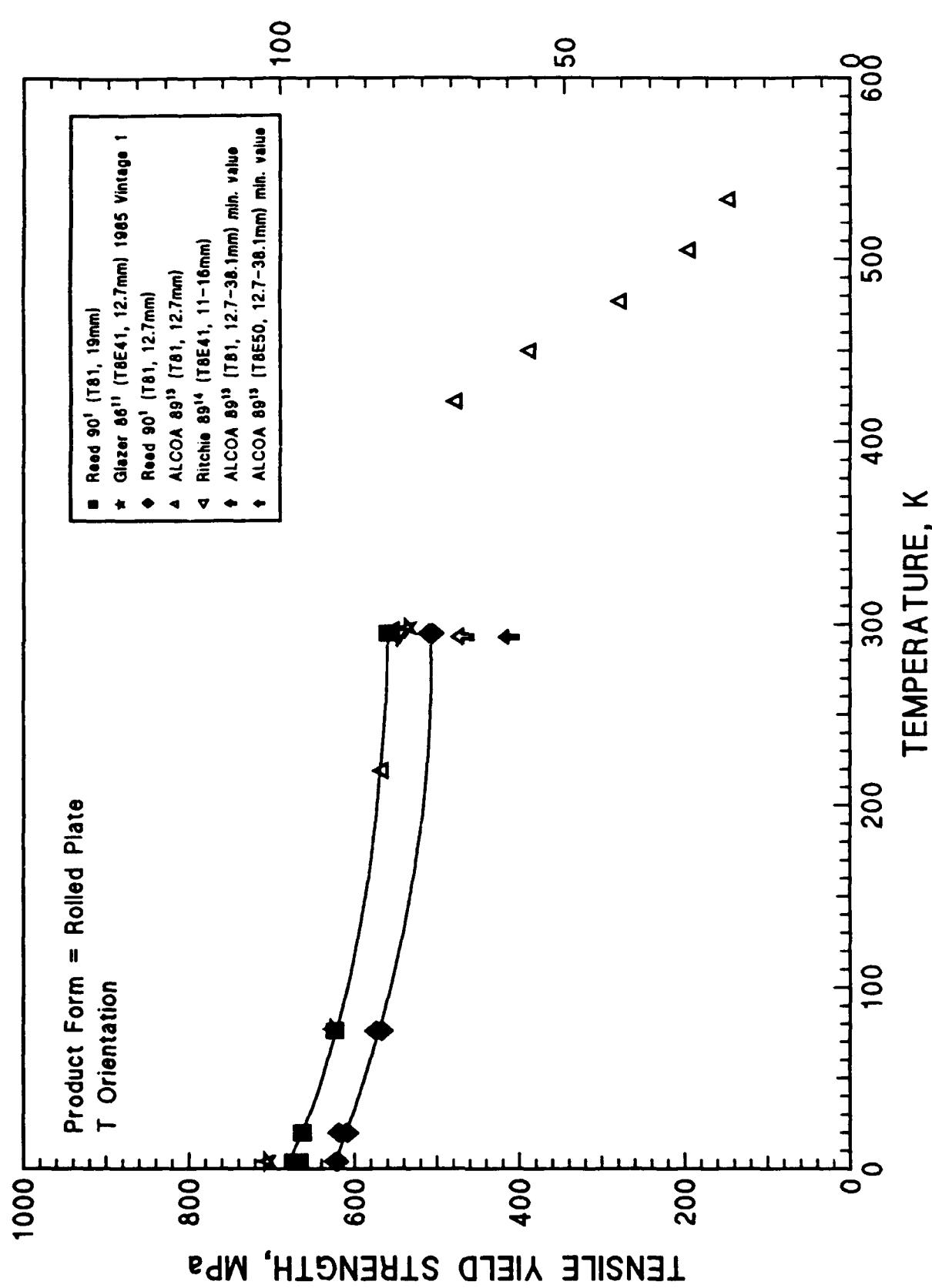
2090-T8



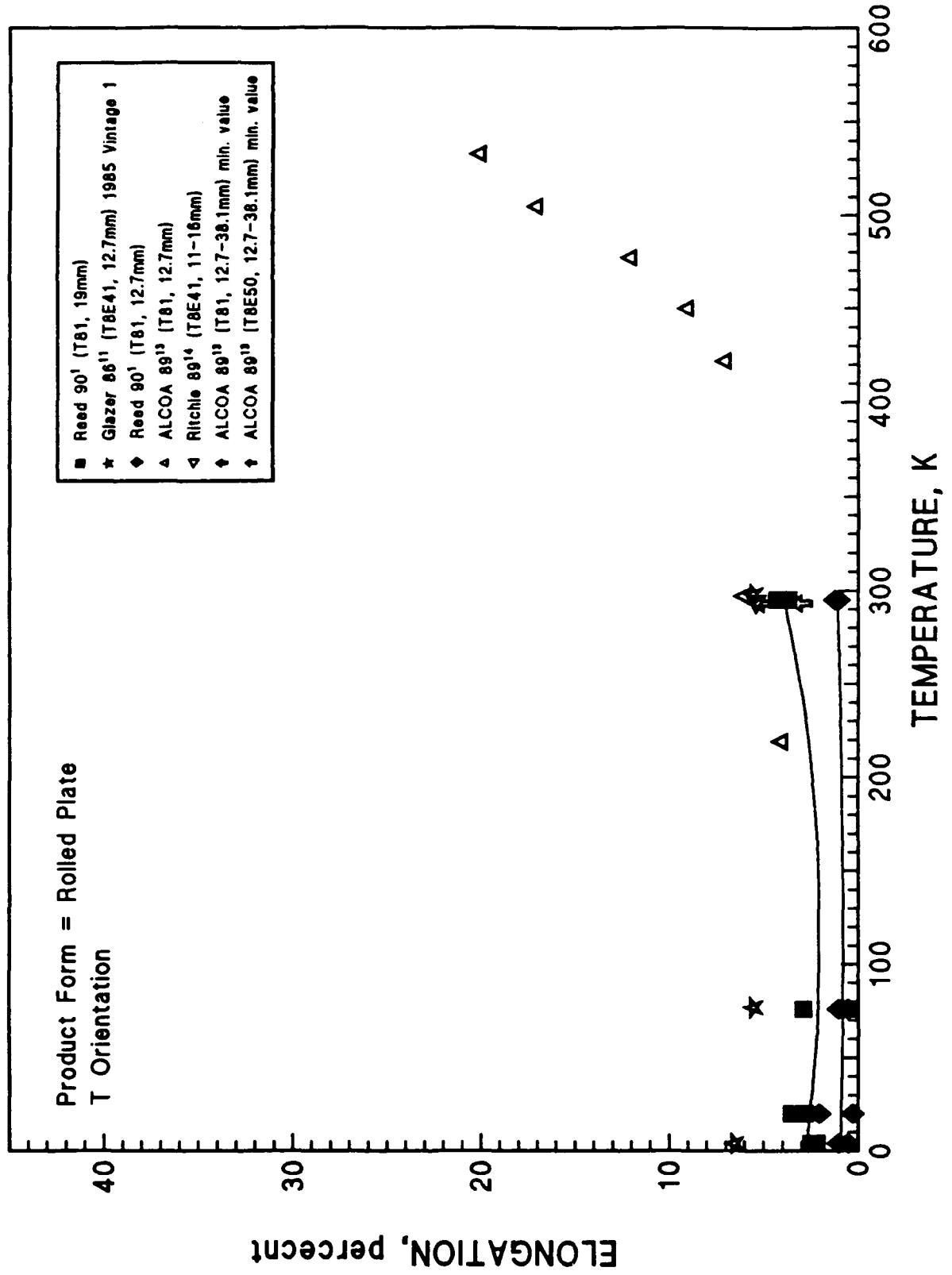
2090-T8



2090-T8

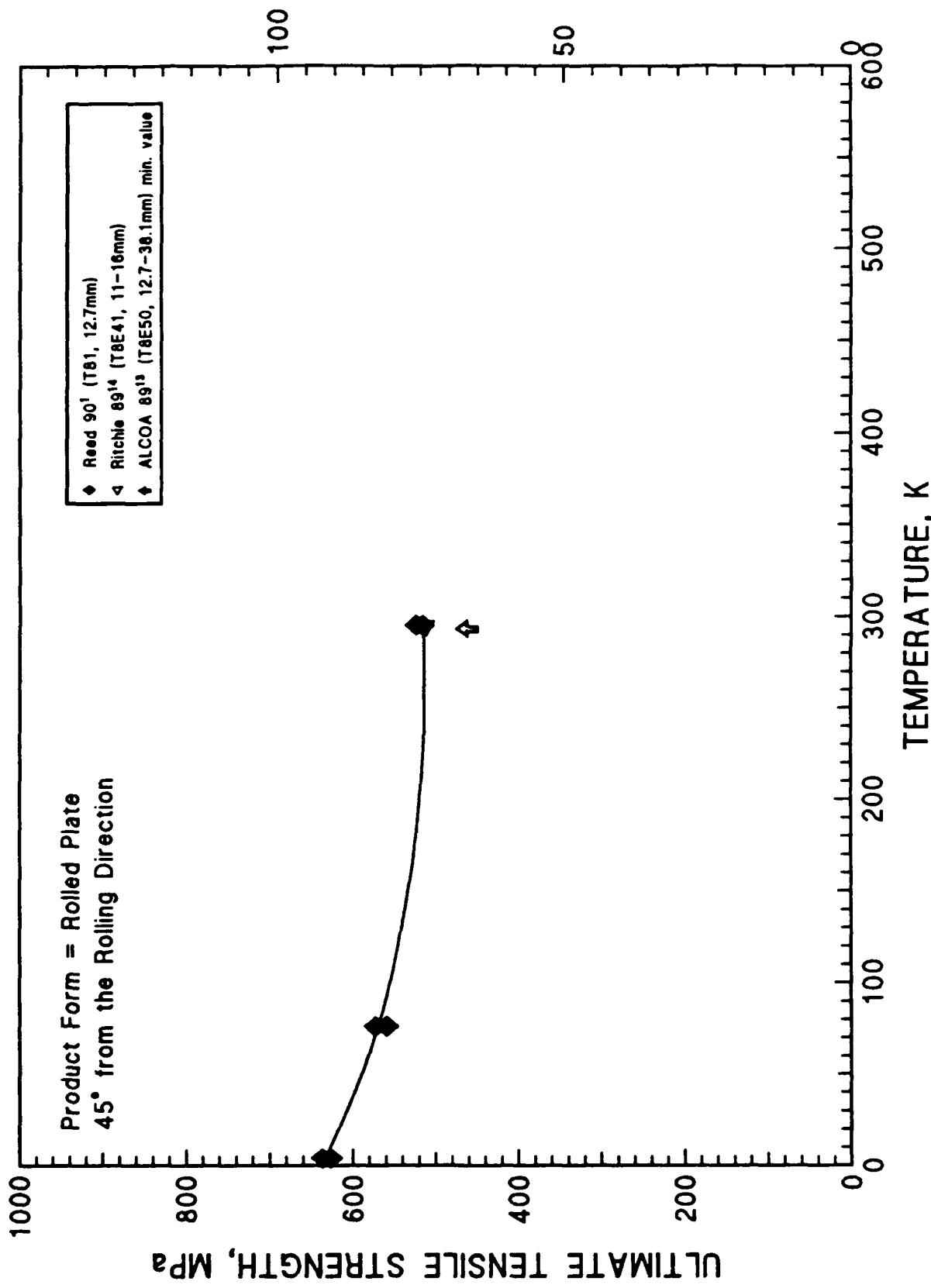


2090-T8



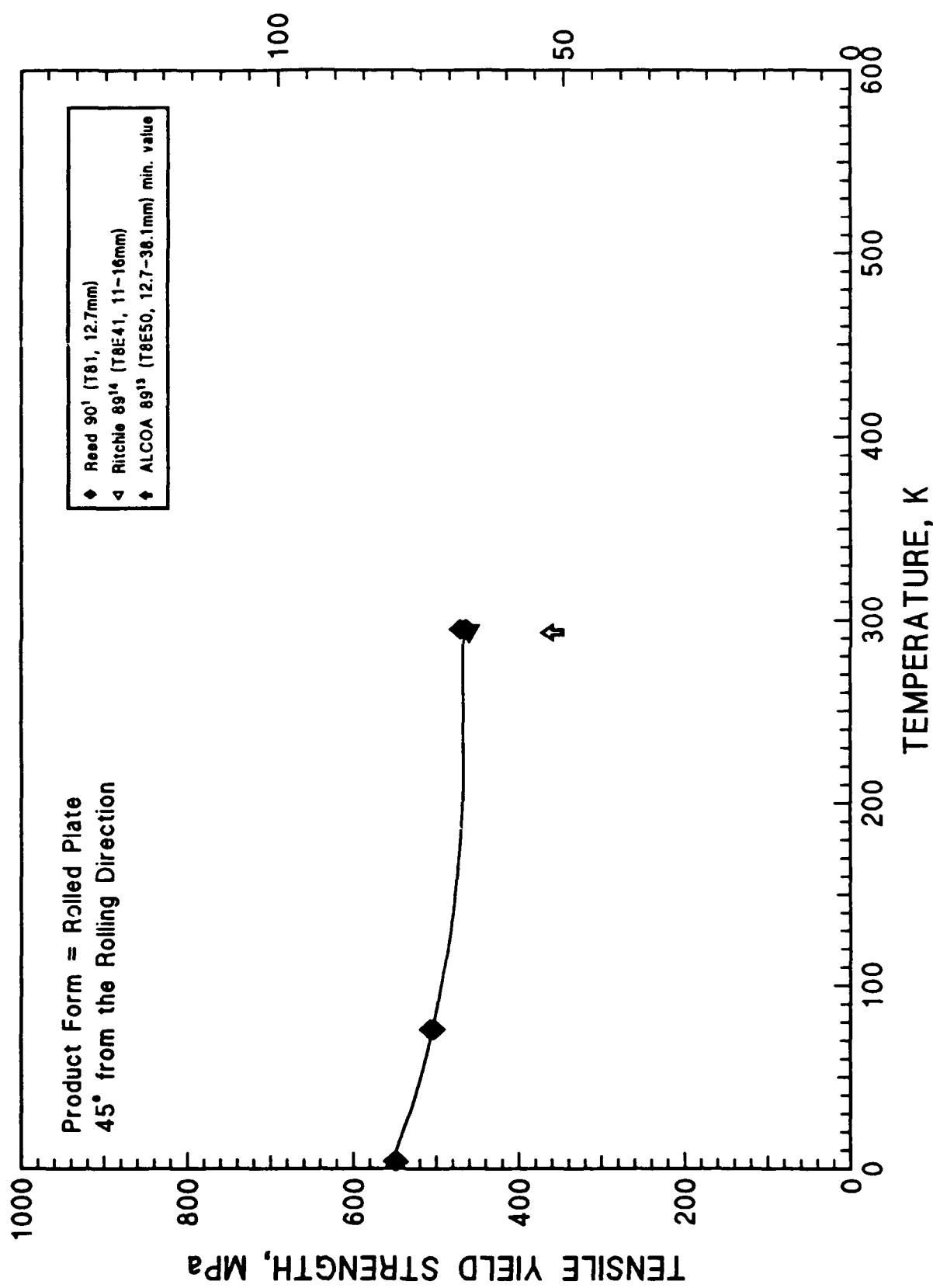
2090-T8

### ULTIMATE TENSILE STRENGTH, ksi



2090-T8

TENSILE YIELD STRENGTH, ksi



2090-T8

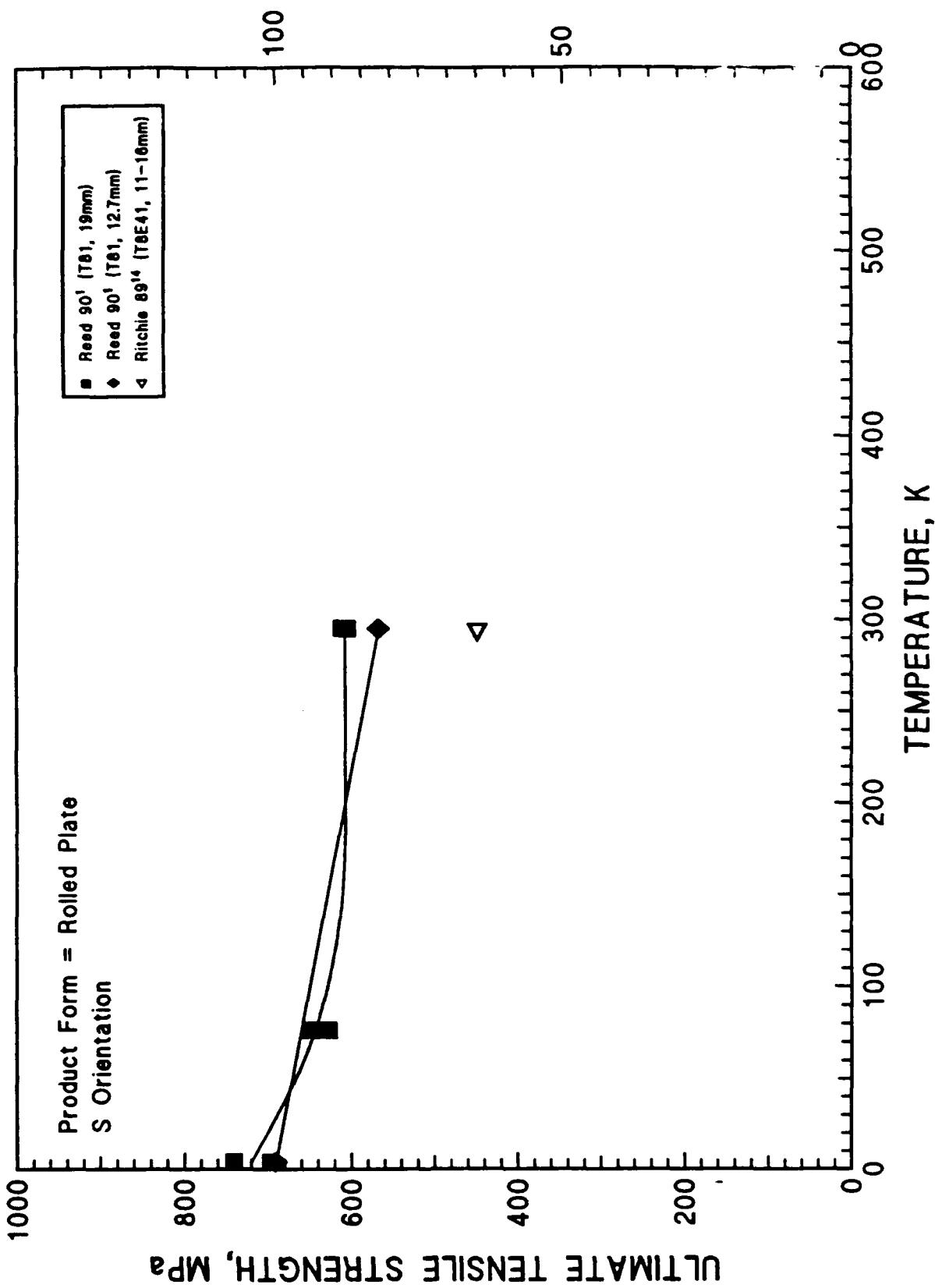
Product Form = Rolled Plate  
45° from the Rolling Direction

- ◆ Reed 90° (T81, 12.7mm)
- ▽ Ritchie 89<sup>14</sup> (T8E41, 11-18mm)
- ◆ ALCOA 89<sup>13</sup> (T8E50, 12.7-38.1mm) min. value

ELONGATION, percent

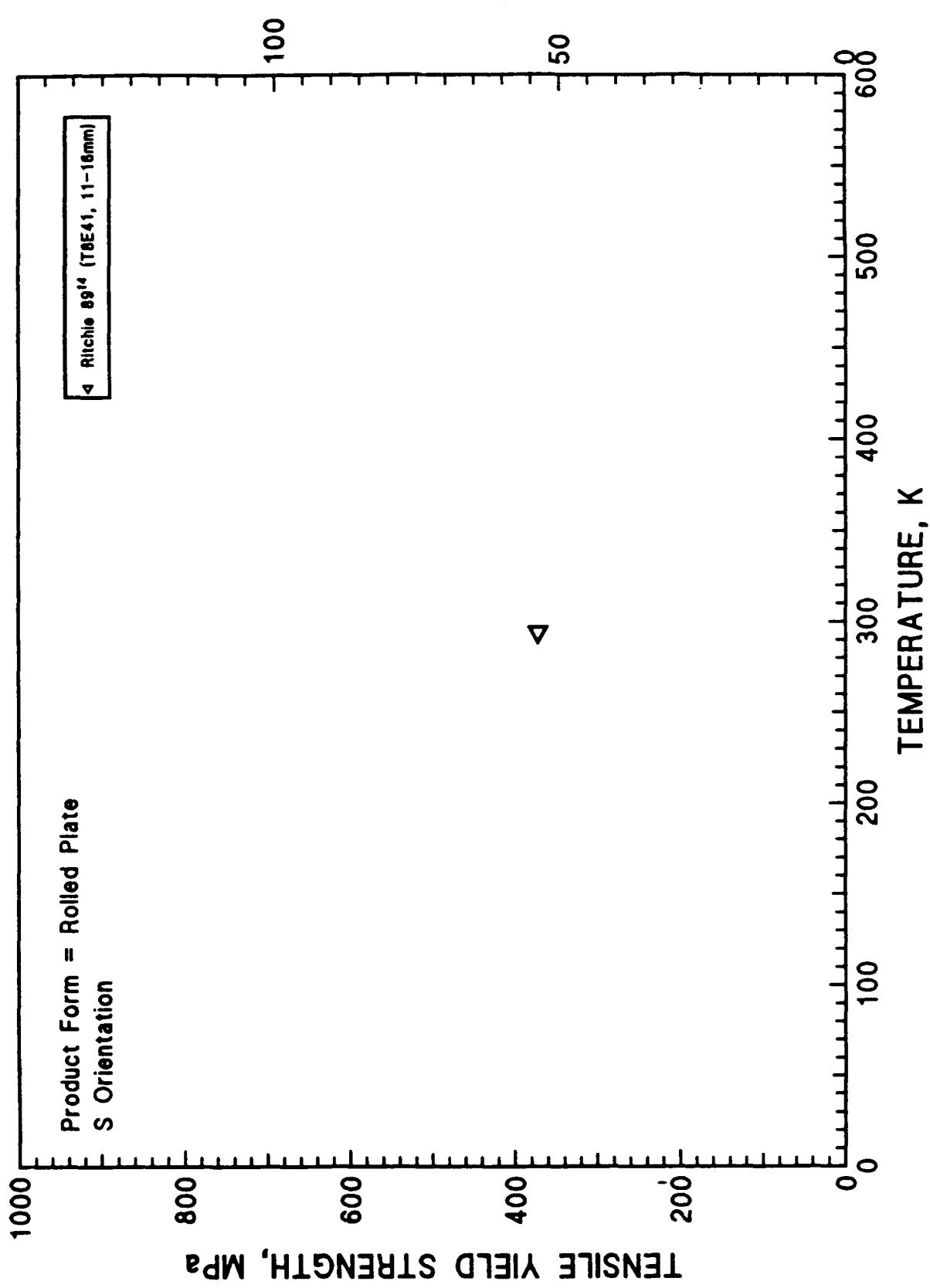
2090-T8

## ULTIMATE TENSILE STRENGTH, ksi



2090-T8

TENSILE YIELD STRENGTH, ksi



2090-T8

Product Form = Rolled Plate  
S Orientation

40

ELONGATION, percent

◀ Ritchie 89<sup>14</sup> (T8E41, 11-16mm)

30

20

10

0

41

600

500

400

300

200

100

0

TEMPERATURE, K

## Al-Li ALLOY 2090

Ref & No.	Temp. K	Y.S. MPa	Elong. %	R.A. %	Orient. L	Temper T61	Product Form	Thickness mm	Aging Time °C	Stretch X h	Solv. Treat. Temp. °C	Quench h	Grain Size μm	Hardness	Tests/ Data Pt.	
1F	285	608.	378.	4.6	17.6	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1F	285	608.	378.	5.0	17.4	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1F	76	746.	673.	6.8	3.45	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1F	76	730.	626.	7.9	0.72	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1F	20	846.	667.	11.8	13.	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1F	20	827.	662.	8.6	9.7	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1F	4	633.	663.	9.2	7.28	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1F	4	889.	660.	6.4	7.35	L	T61	Rolled Plate	19.05	MA	NA	NA	NA	NA	198.3	1
1H	285	532.	502.	4.8	6.9	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
1H	285	529.	500.	4.2	11.6	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
1H	76	623.	555.	7.2	7.9	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
1H	20	686.	586.	6.9	11.9	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
1H	76	609.	546.	4.8	10.6	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
1H	20	743.	584.	8.9	8.86	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
1H	4	692.	608.	6.5	20.3	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
1H	4	684.	592.	6.9	13.7	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	198.3	1
13A	293	552.	517.	8.	NA	L	T61	Rolled Plate	6.35-50.6	NA	NA	NA	NA	NA	*	
13B	533	138.	117.	25.	NA	L	T61	Rolled Plate	12.7	MA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Product Form	Thickness mm	Aging Temp. °C	Time h	Stretch Z	Temp. °C	Time h	Quench Cond.	Grain Size μm	Soln. Treat.	Hardness	No. of Tests/ Data Pt.
13B 505	193.	165.	10.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13B 477	290.	262.	20.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	2
13B 450	365.	359.	15.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13B 422	462.	462.	16.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13B 297	593.	558.	6.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13C 293	517.	483.	4.	NA	L	T81	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	*	
12A 219	614.	565.	NA	NA	L	T8	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
12A 77	715.	600.	13.5	NA	L	T8	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13A 293	490.	441.	4.	NA	L	T8E50	Rolled Plate	6.35-50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	*
13C 293	490.	434.	5.	NA	L	T8E50	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	*
11A 77	715.	600.	13.5	NA	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
11A 4	820.	615.	17.5	NA	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
14A 293	589.	552.	9.3	NA	L	T8E41	Rolled Plate	11-16	163	24.	6	NA	NA	NA	L:2500*; T:500; S:50	NA	1	
15A 298	565.	535.	11.	NA	L	T8E41	Rolled Plate	13	163	24.	6	NA	NA	NA	NA	NA	NA	1
16A 298	490.	455.	6.	NA	L	T8E41	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
16A 77	625.	505.	14.	NA	L	T8E41	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
16A 4	650.	535.	20.	NA	L	T8E41	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
17A 295	555.	535.	9.	15.	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
17A 76	666.	595.	6.	8.	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & No.	Note	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. z	Temper T6E41	Product Form	Thickness mm	Product Temp. °C	Aging Time h	Soln. Temp. °C	Stretch Z	Quench h	Treat. Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt.
17A	4	737.	626.	6.	11.	L	T6X	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
6B	300	548.	503.	14.	MA	L	T6X	Rolled Plate	12.7	190	4.	2	550	1.	NA	NA	NA	NA	1
6B	300	542.	507.	12.	MA	L	T6X	Rolled Plate	12.7	190	8.	2	550	1.	NA	NA	NA	NA	1
6B	77	630.	564.	15.	MA	L	T6X	Rolled Plate	12.7	190	8.	2	550	1.	NA	NA	NA	NA	1
6B	77	619.	525.	17.	MA	L	T6X	Rolled Plate	12.7	190	4.	2	550	1.	NA	NA	NA	NA	1
16B	296	270.	120.	19.	MA	L	T4	Rolled Plate	3.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
16B	77	350.	155.	29.	MA	L	T4	Rolled Plate	3.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
16B	4	435.	190.	25.	MA	L	T4	Rolled Plate	3.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1F	295	595.	557.	3.7	12.5	T	T61	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	295	600.	561.	4.3	13.3	T	T61	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	76	688.	624.	0.4	3.51	T	T61	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	76	699.	623.	2.9	5.16	T	T61	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	20	761.	664.	3.5	7.53	T	T61	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	20	767.	662.	2.8	5.97	T	T61	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	4	754.	666.	2.2	5.56	T	T61	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	295	544.	509.	1.	3.04	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	295	548.	505.	1.2	6.12	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	76	611.	573.	1.	4.93	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. I Z	Temper T61	Product Form	Thickness mm	Temp. °C	Time h	Stretch I	Quench h	Soln. Treat. Cond.	Grain Size μm	Hardness	Tests/ Data Pt.	
1H	76	609.	566.	0.5	3.26	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1B	20	632.	618.	2.	2.09	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1B	20	691.	608.	0.25	2.96	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1B	4	668.	620.	0.5	3.68	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	4	670.	622.	1.	3.91	I	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1B	533	165.	145.	20.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	505	228.	193.	17.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	477	296.	276.	12.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	2
1B	450	476.	386.	9.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	422	476.	386.	7.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	297	586.	552.	6.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	4
1B	219	607.	585.	4.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	293	517.	469.	3.	NA	T	T61	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	*
1C	293	490.	414.	5.	NA	T	T6E50	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	*
1B	298	565.	535.	5.5	NA	T	T6E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	77	665.	625.	5.5	NA	T	T6E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	4	815.	705.	6.5	NA	T	T6E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1AA	293	579.	548.	5.4	NA	T	T6E41	Rolled Plate	11-16	163	24.	6	NA	NA	NA	L:2500*; T:500; S:50	NA	1
1H	295	515.	463.	4.	9.	45°	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Soln. Treat. Time °C	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt.
1H	295	523.	470.	6.	11.	45*	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	76	558.	502.	3.	7.	45*	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	76	572.	506.	4.	7.	45*	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	4	636.	550.	5.	6.	45*	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	4	628.	547.	5.	10.	45*	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1C	293	462.	359.	6.	MA	45*	T6E50	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	*
1A	293	514.	460.	10.9	MA	45*	T6E41	Rolled Plate	11-16	163	24.	6	NA	NA	L:2500*, T:500; S:50	NA
1G	295	604.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	295	611.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	76	627.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	76	649.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	4	741.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	4	697.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1I	295	568.	NA	NA	NA	S	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1I	4	690.	NA	NA	NA	S	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
14B	293	448.	372.	1.	NA	S	T6E41	Rolled Plate	11-16	163	24.	6	NA	NA	L:2500*, T:500; S:50	NA

\*See Comments

Comments from the Al-Li Alloy 2090 Data Table

Reference and  
Note Number

13A--Values reported are "typical" properties.

13C--Values reported are "minimum" properties.

13E--Values reported are "minimum" properties.

14A--Value reported is the average of the range of grain sizes.

14B--Value reported is the average of the range of grain sizes.

15A--Value reported is the average of the range of grain sizes.

**TEST PARAMETERS**  
**Al-Li ALLOY 2090**

Ref & Note No.	Strain Rate	Specimen			Supplier	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements				Minor Elements wt%						
		Type	Diam	Thick					G.I. mm	min	Location	Li	Cu	Mg	Zr	Si	Fe	As	
1F	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcoa	1969	103299	1.22 X 2.44	2.3	2.6	0.1	0.1	NA	0.07	NA	NA
1G	2.2	Round	2.5	NA	25.4	Random	5.	Alcoa	1969	103299	1.22 X 2.44	2.3	2.6	0.1	0.1	NA	0.07	NA	NA
1H	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcoa	1969	103301	1.22 X 2.44	2.3	2.7	0.	0.12	NA	0.08	NA	NA
1I	2.2	Round	2.5	NA	25.4	Random	5.	Alcoa	1969	103301	1.22 X 2.44	2.3	2.7	NA	0.12	NA	0.08	NA	NA
6B	1.0	Round	NA	NA	NA	NA	15.	Alcoa	NA	NA	NA	2.53	1.6	0.5	0.13	0.3	0.3	NA	NA
11A	NA	Round	NA	NA	25.4	NA	NA	Alcoa	NA	NA	NA	2.2*	2.7	NA	0.12	NA	NA	NA	NA
11B	NA	Round	NA	NA	25.4	NA	NA	Alcoa	NA	NA	NA	2.2*	2.7	NA	0.12	NA	NA	NA	NA
54	12A	NA	NA	NA	NA	NA	NA	Alcoa	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
13A	NA	Flat	NA	NA	NA	Random	NA	Alcoa	NA	NA	NA	2.3*	2.7	0.3	0.12	0.1	0.12	NA	Ti:0.15;Zn:0.10;Cr:0.05
13B	NA	Flat	NA	NA	NA	Random	NA	Alcoa	NA	NA	2.34	2.3*	2.7	0.3	0.12	0.1	0.12	NA	Ti:0.15;Zn:0.10;Cr:0.05
13C	NA	Flat	NA	NA	NA	Random	NA	Alcoa	NA	NA	NA	2.3*	2.7	0.3	0.12	0.1	0.12	NA	Ti:0.15;Zn:0.10;Cr:0.05
14A	NA	Round	6.4	NA	25.	Mid-plane	NA	Alcoa	NA	NA	NA	2.1*	2.9	0.	0.12	E-2	0.02	NA	Zn:0.005; Ti:0.02
14B	NA	Round	6.4	NA	25.	Mid-plane	NA	Alcoa	NA	NA	NA	2.1*	2.9	0.	0.12	E-2	0.02	NA	Zn:0.005; Ti:0.02
15A	NA	NA	NA	NA	NA	NA	NA	Alcoa	NA	NA	NA	2.05	2.9	0.	0.12	E-2	0.02	NA	Na:0.05; Ti:0.02
16A	0.0	Flat	9.5	3.2	41.	to the thickness	NA	Alcoa	NA	NA	NA	2.05	2.9	NA	0.12	NA	NA	NA	NA
16B	0.0	Flat	9.5	3.2	41.	to the thickness	NA	Alcoa	NA	NA	NA	2.05	2.9	NA	0.12	NA	NA	NA	NA
17A	2.2	Round	6.35	NA	25.4	NA	5.	Alcoa	NA	NA	1.22 X 1.22	2.05	2.9	NA	0.12	NA	NA	NA	NA

Comments from the Al-Li Alloy 2090 Test Parameter Table

Reference and  
Note Number

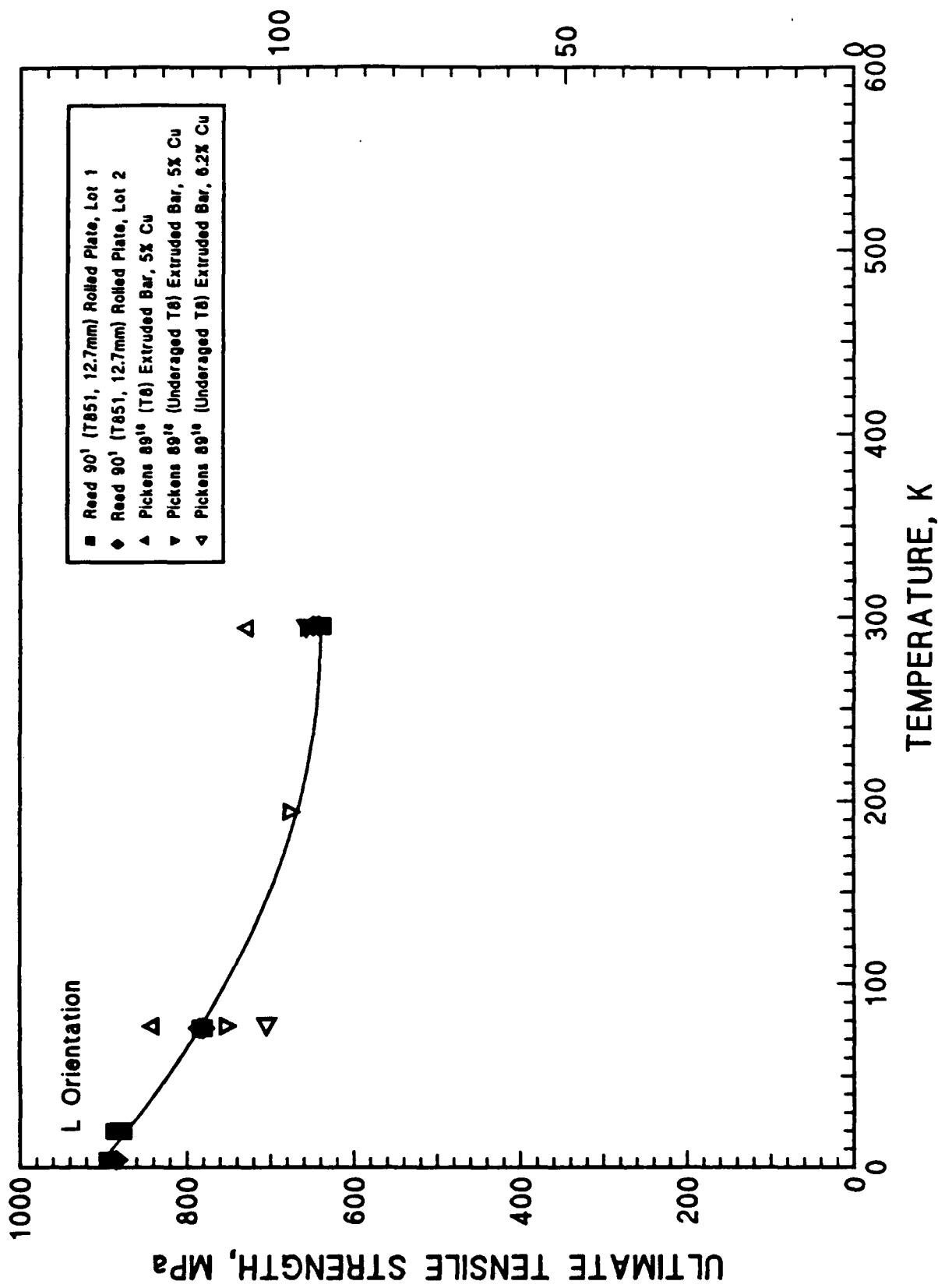
11A--Reported composition is based on nominal values.

13A-C--Reported composition is the average of the minimum and maximum values.

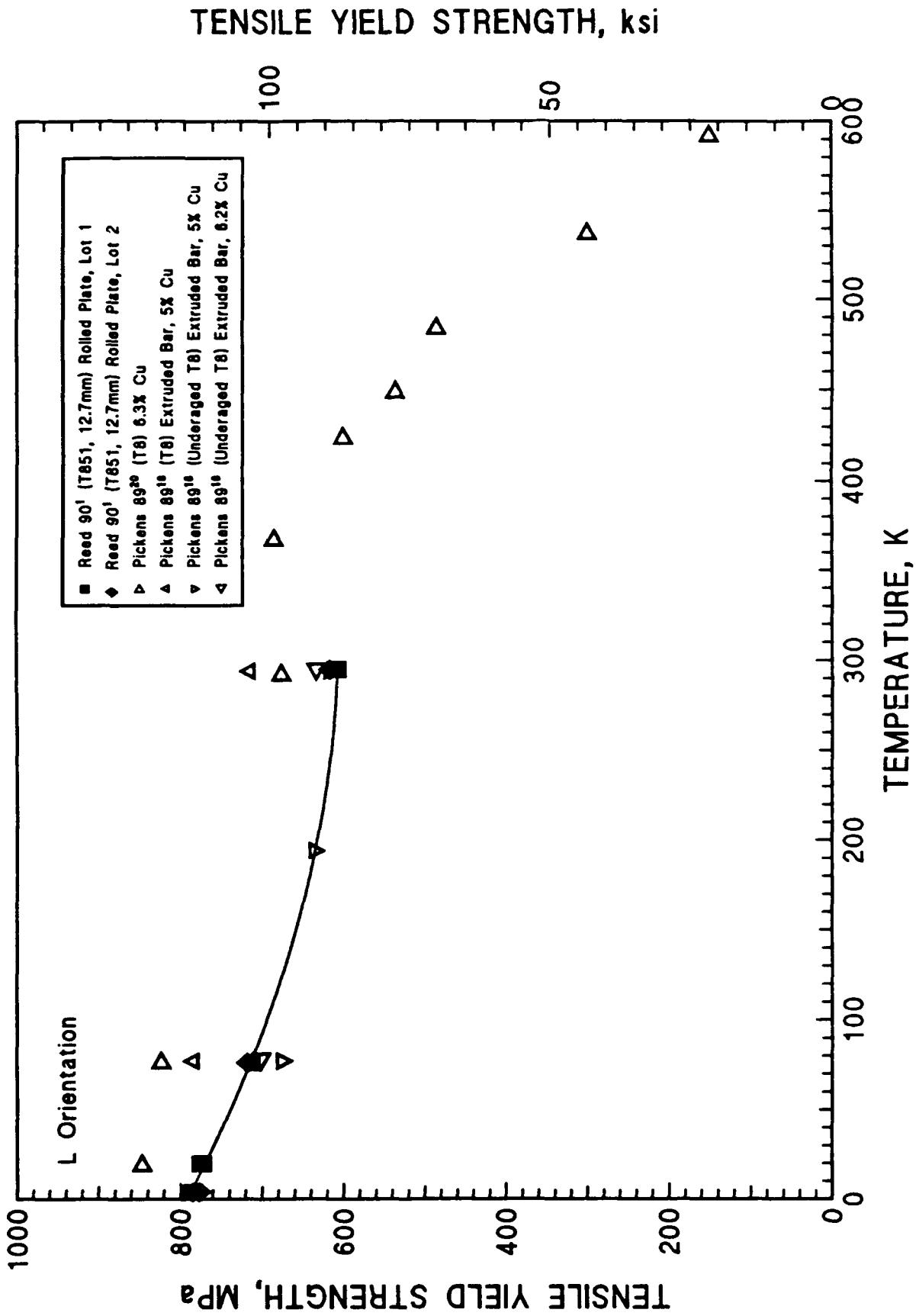
14A--Reported composition is based on nominal values.

# WL049-T8

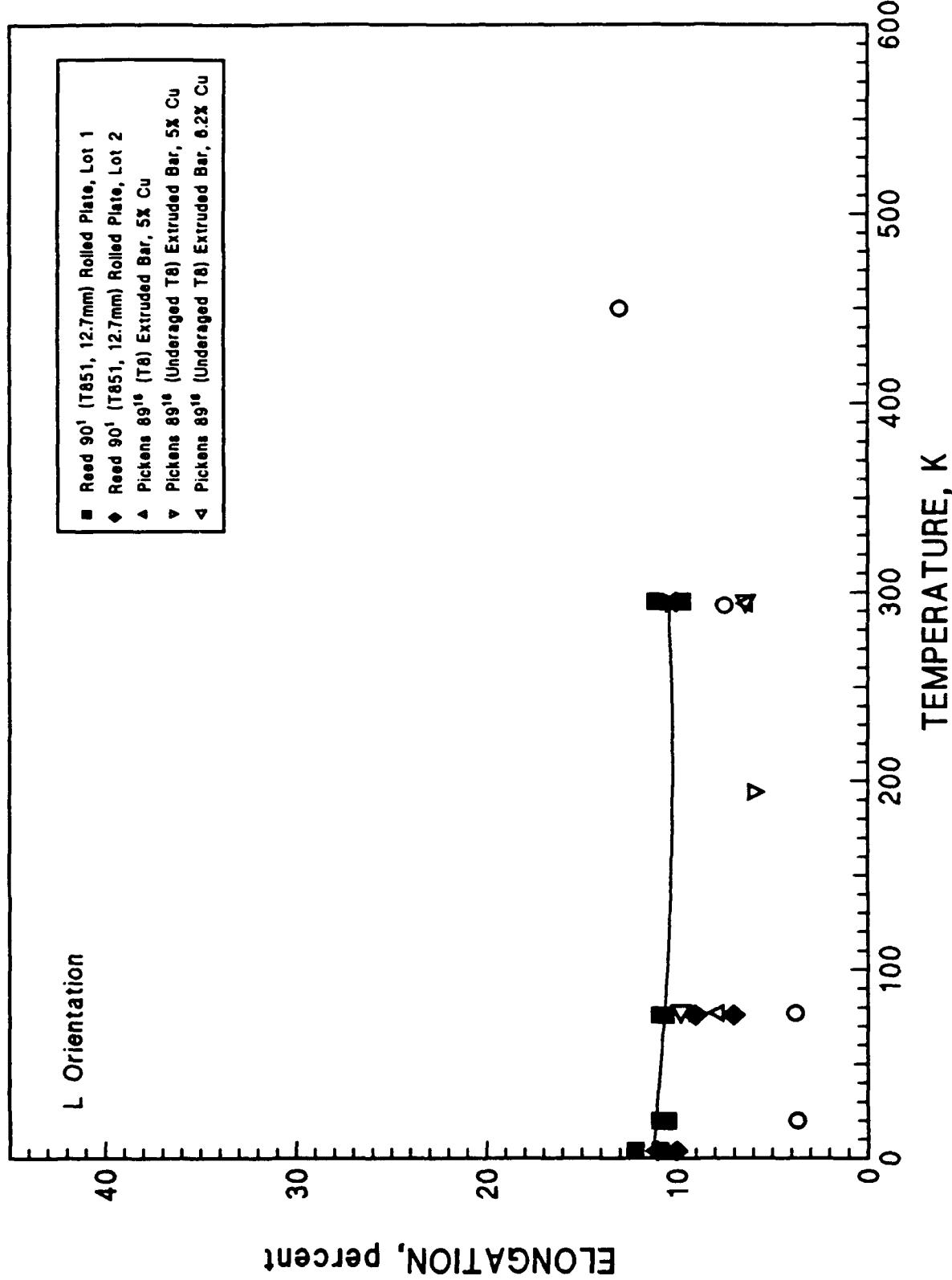
## ULTIMATE TENSILE STRENGTH, ksi



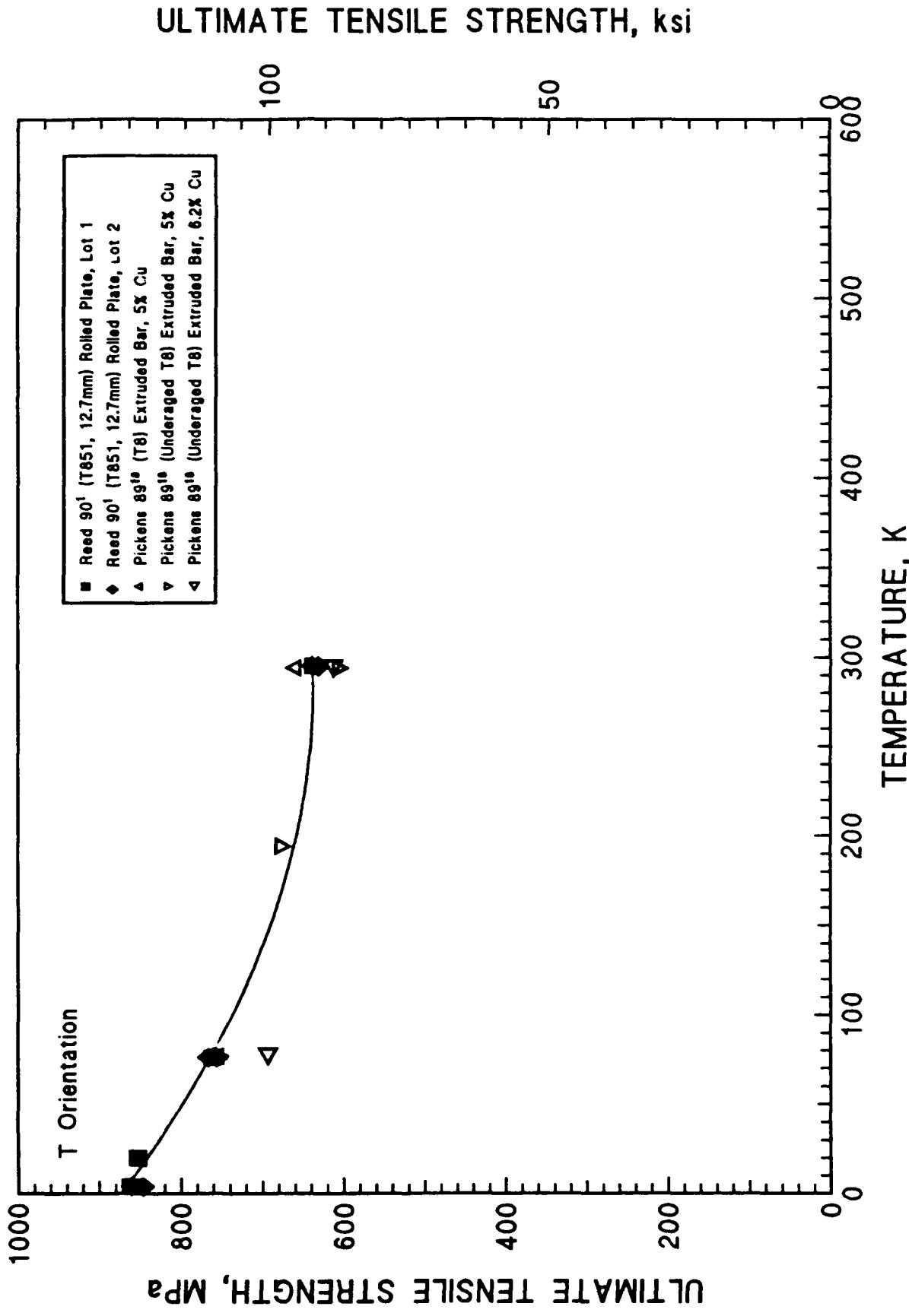
WL049-T8



# WL049-T8

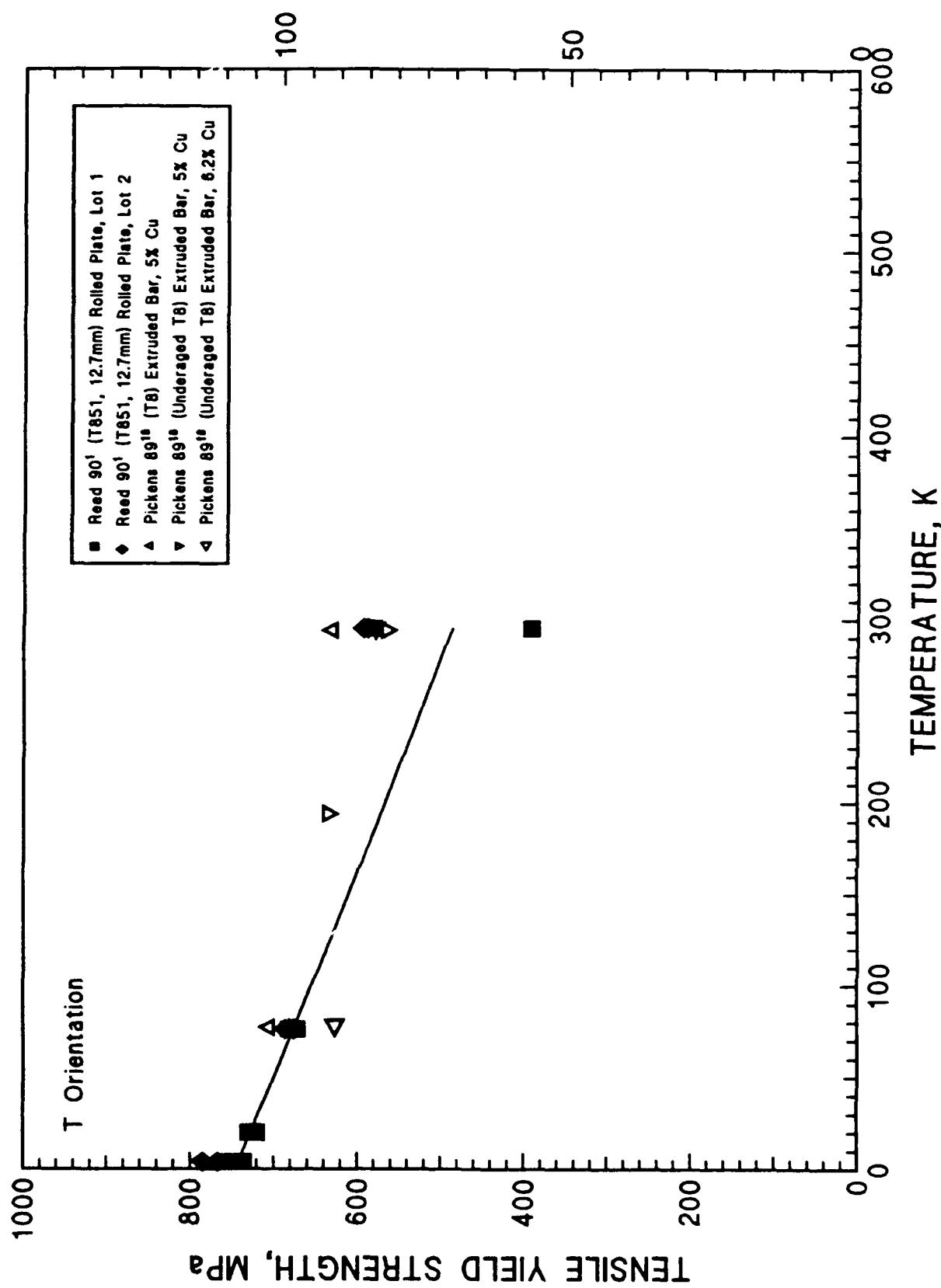


WL049--T8

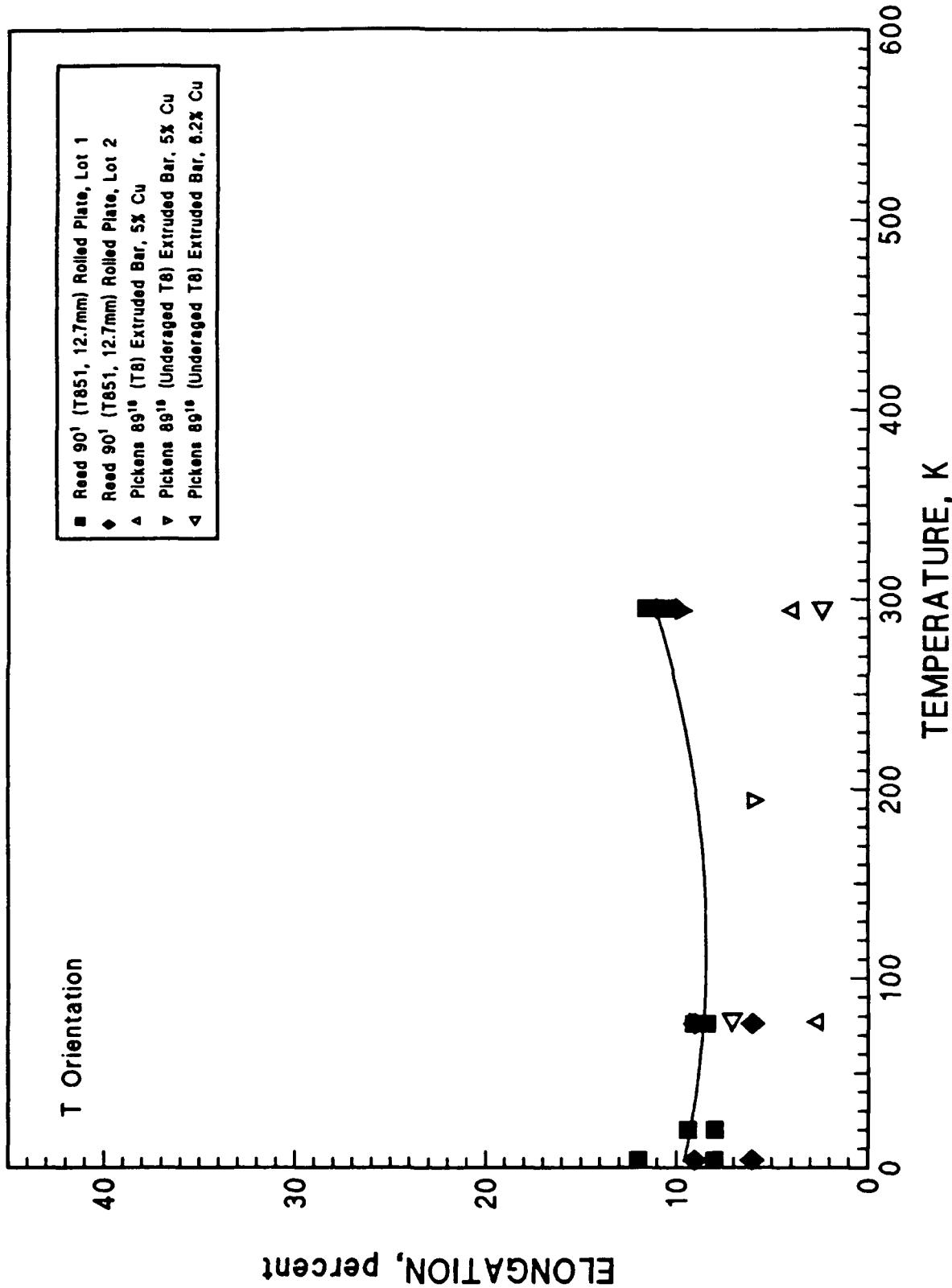


# WL049-T8

## TENSILE YIELD STRENGTH, ksi

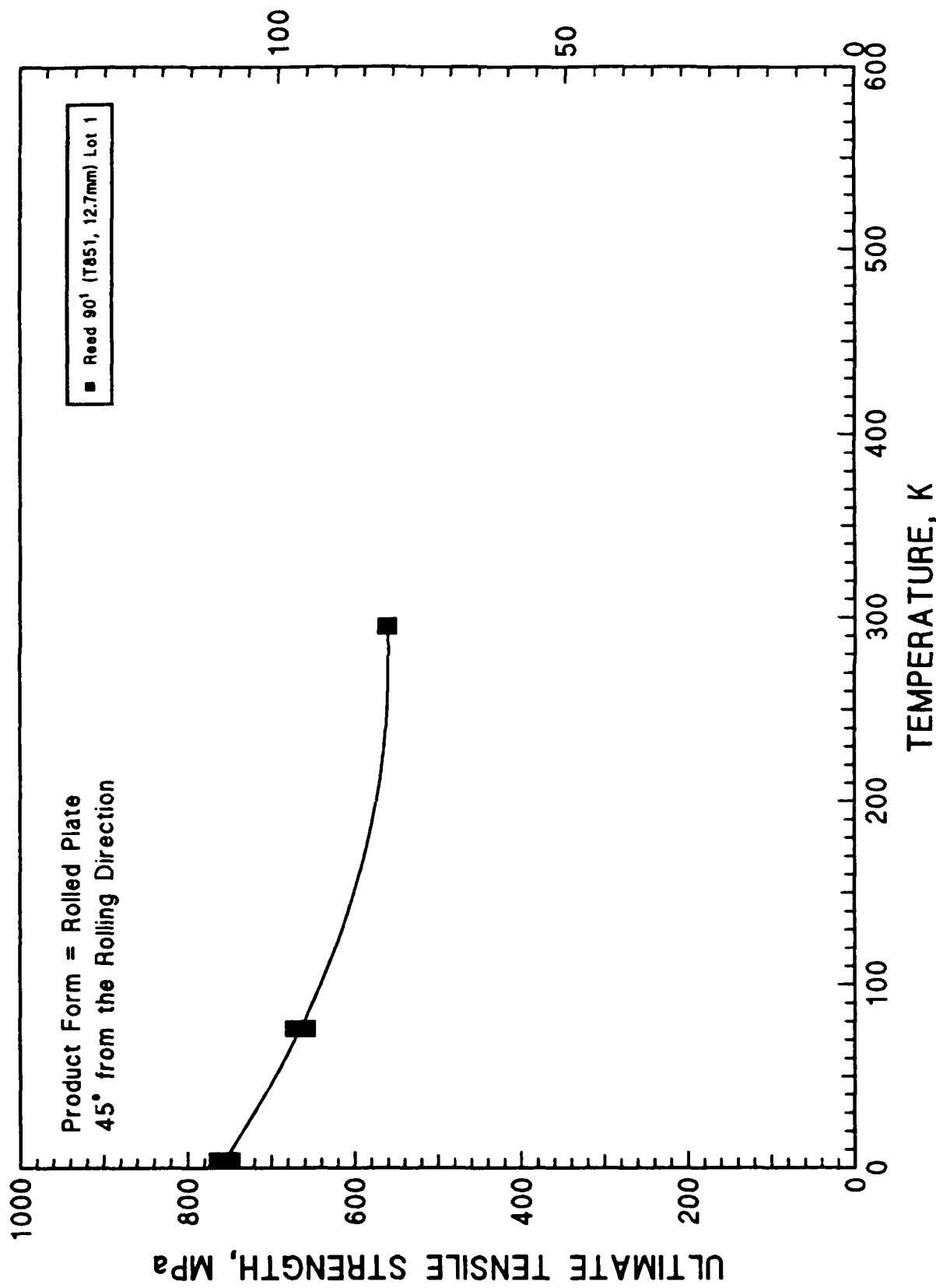


# WL049-T8



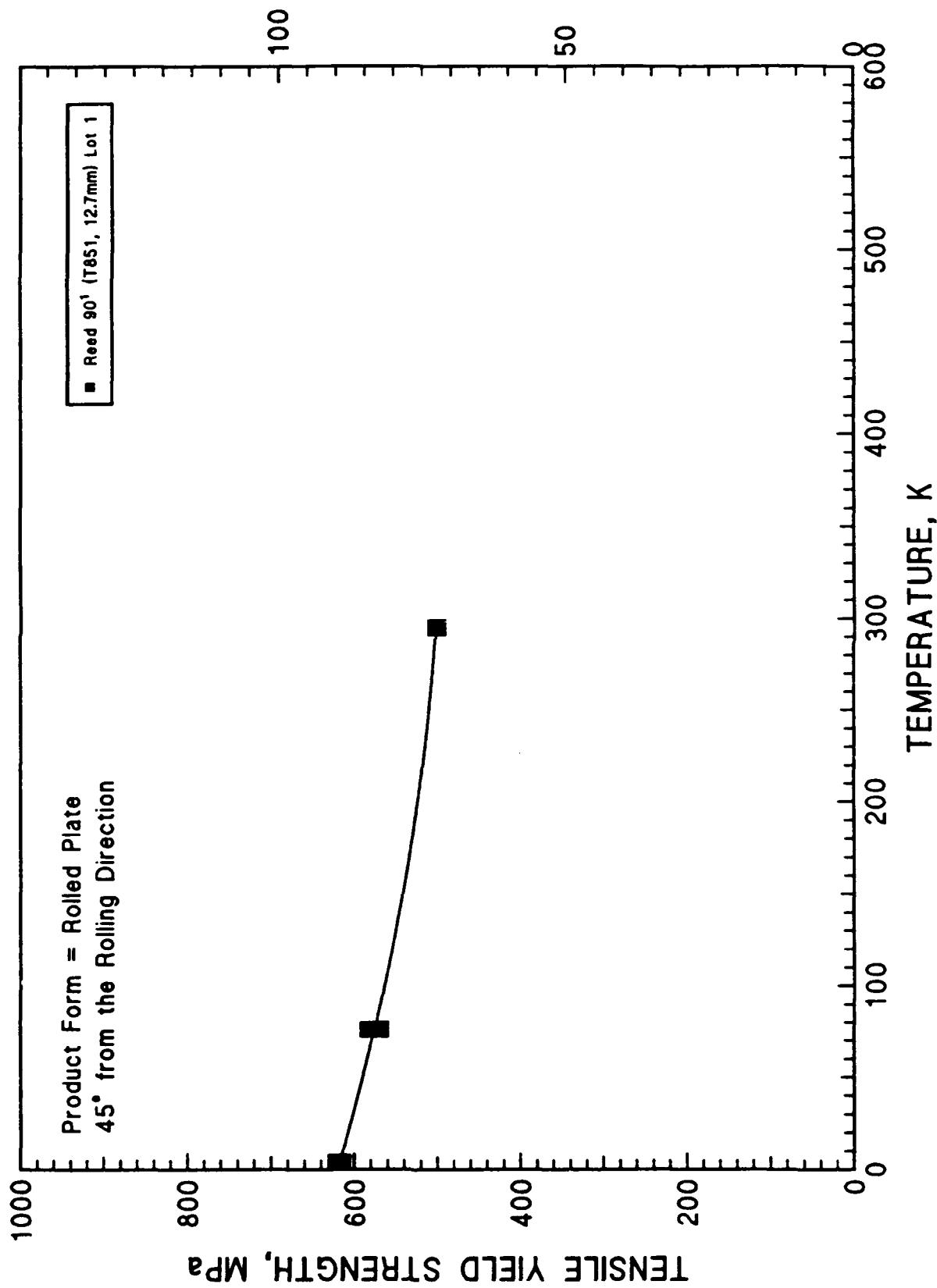
WL049-T8

ULTIMATE TENSILE STRENGTH, ksi



WL049-T8

TENSILE YIELD STRENGTH, ksi



WL049-T8

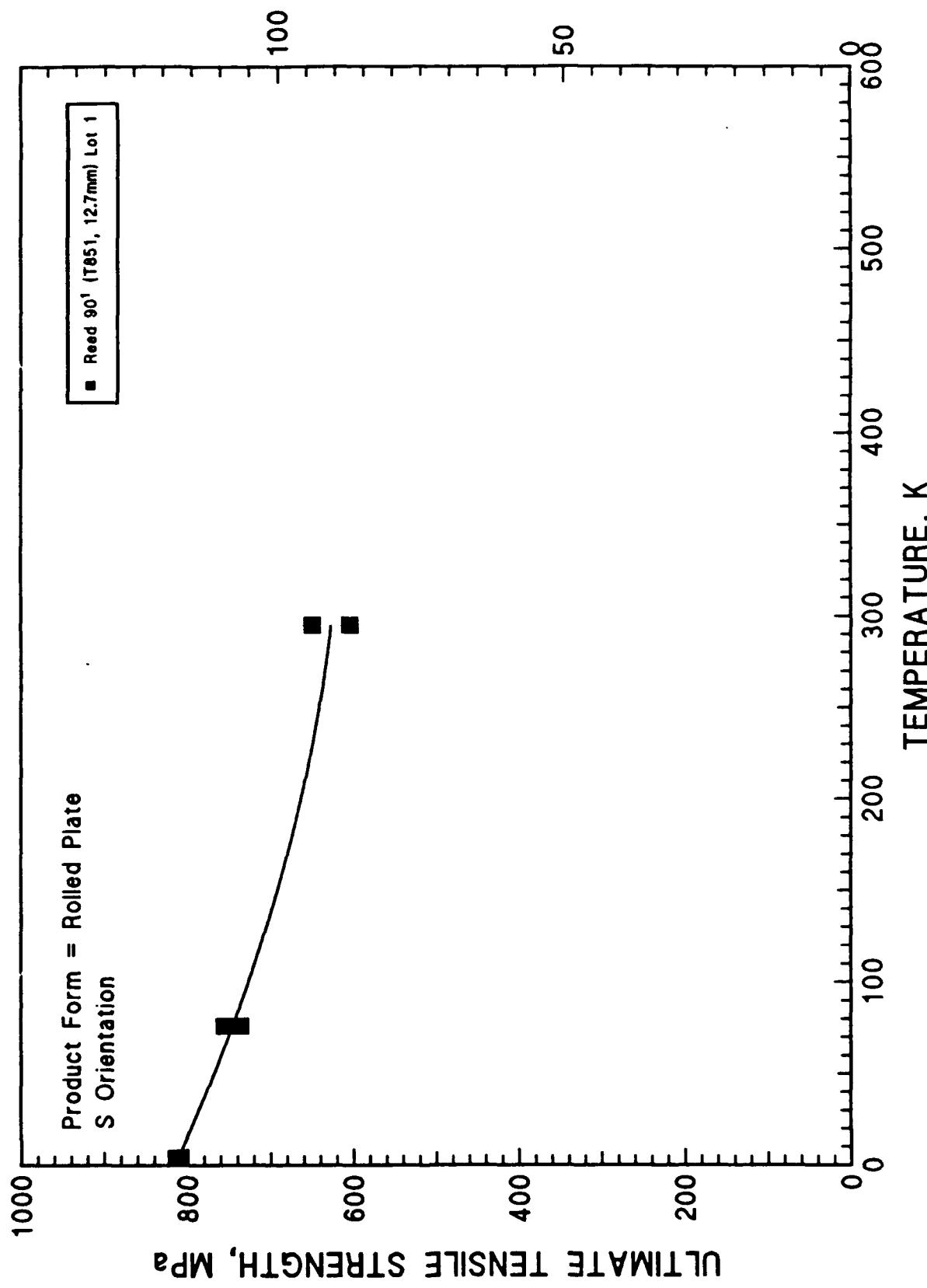
Product Form = Rolled Plate  
45° from the Rolling Direction

■ Reed 90' (T851, 12.7mm) Lot 1

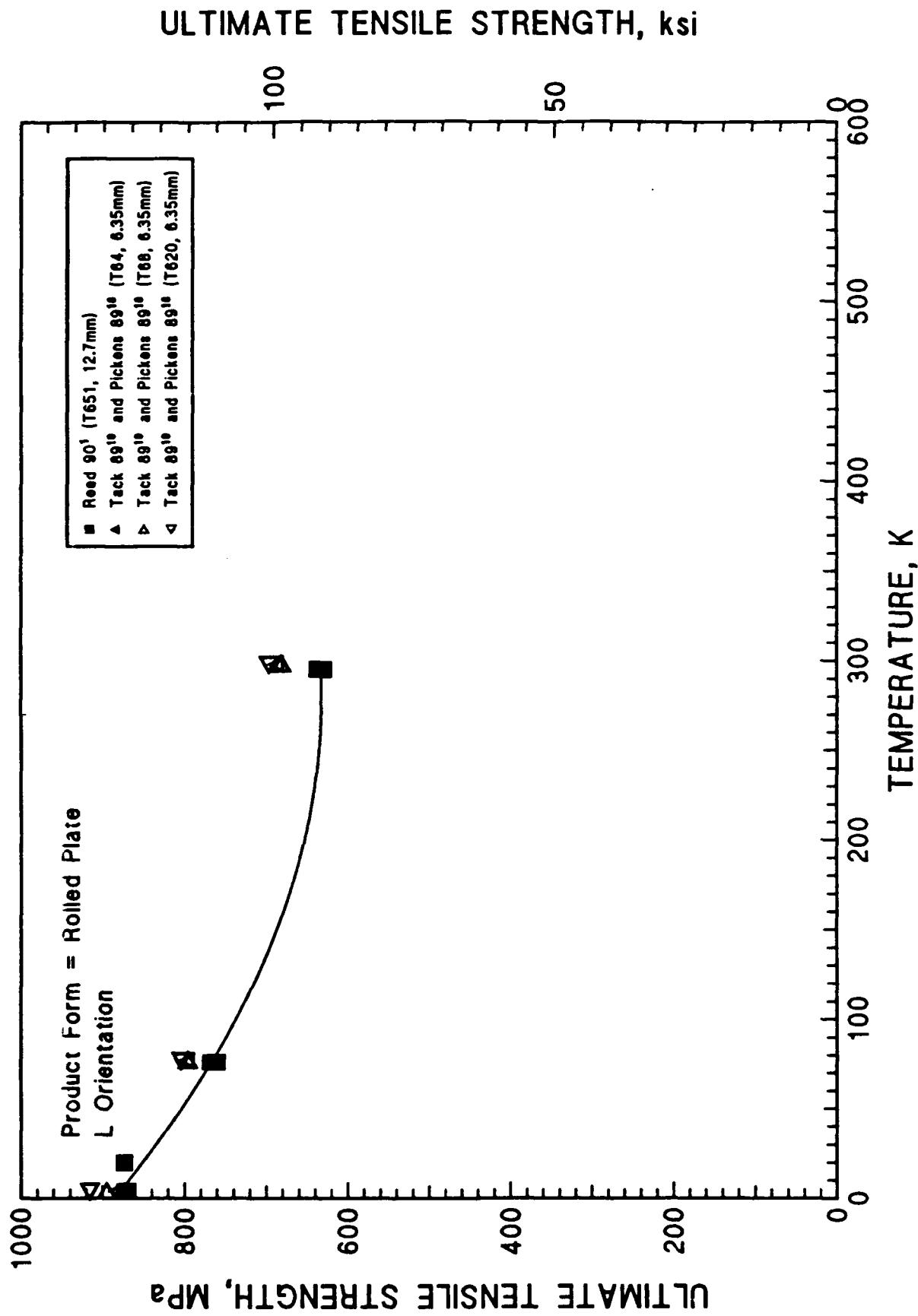
ELONGATION, Percent

WL049-T8

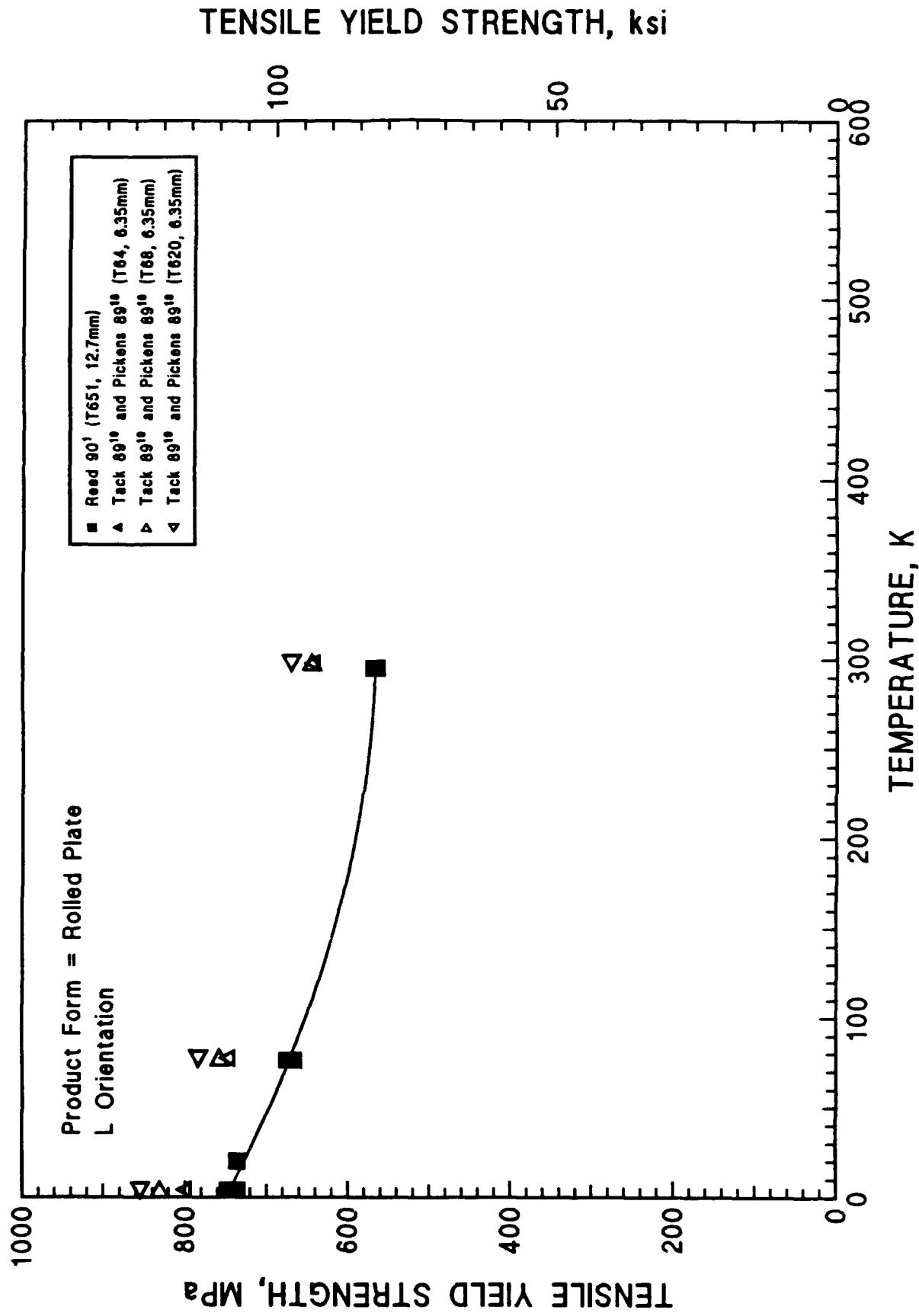
ULTIMATE TENSILE STRENGTH, ksi



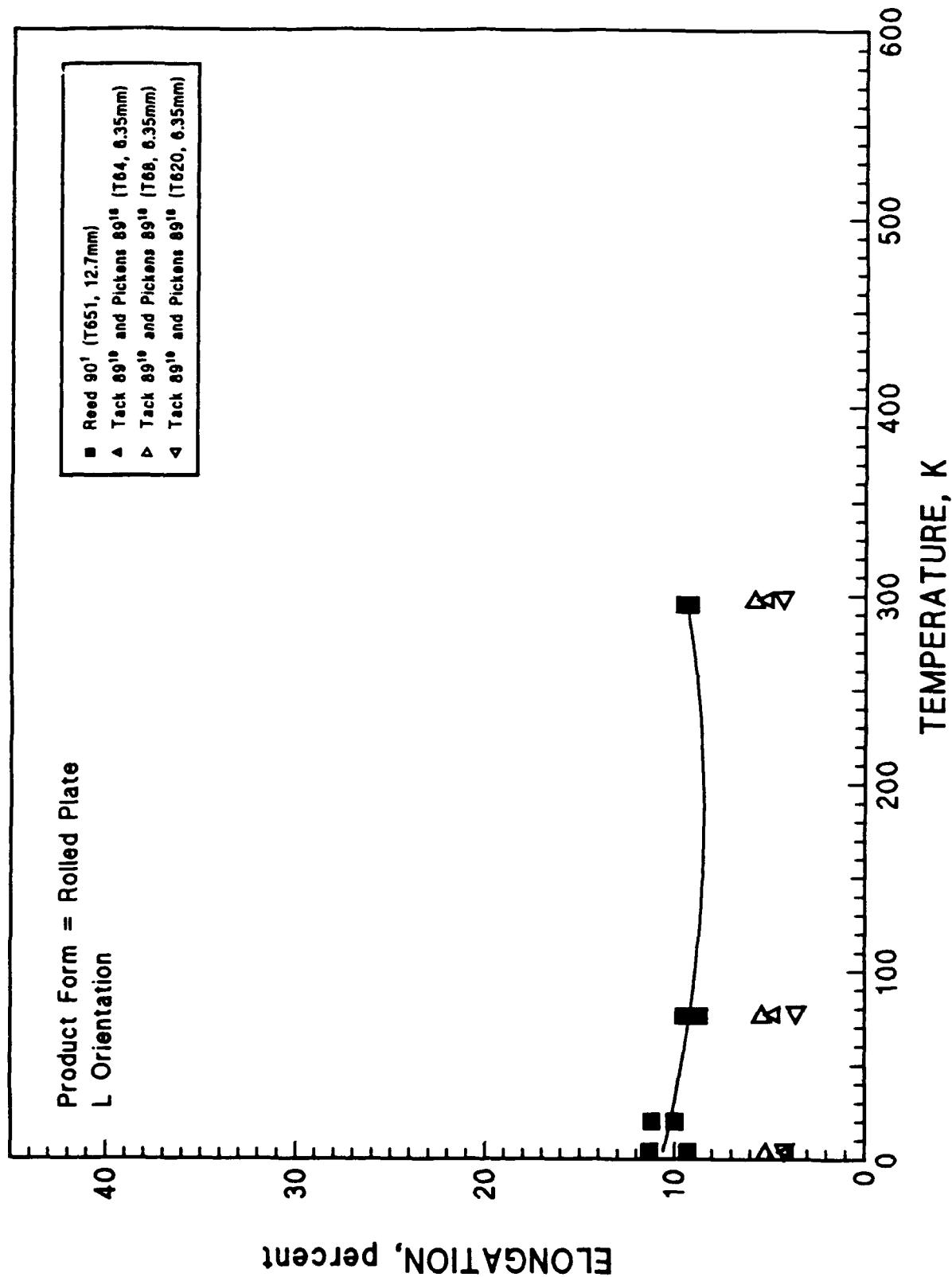
WL049-T6



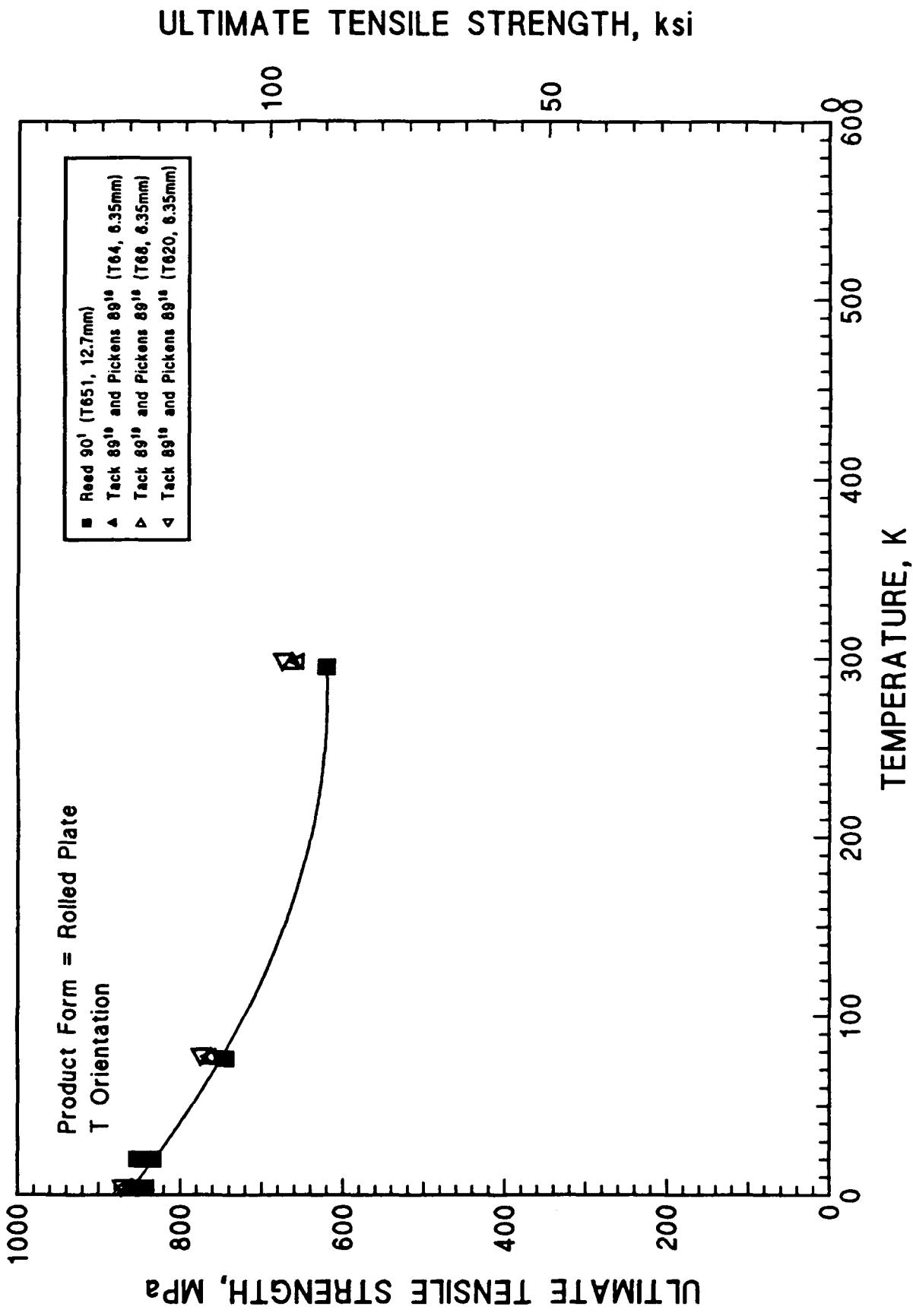
WL049-T6



# WL049-T6

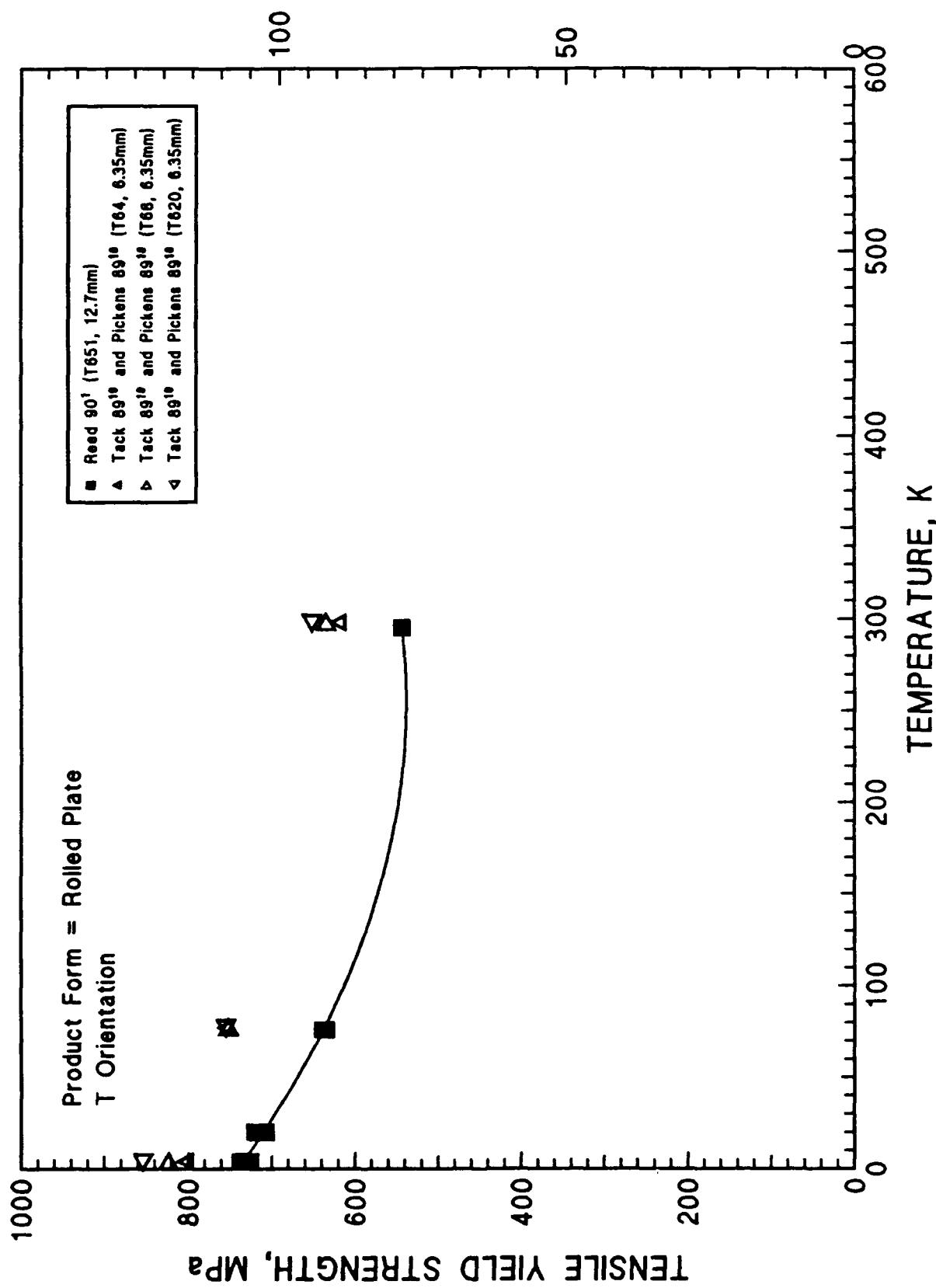


WL049-T6



# WL049-T6

## TENSILE YIELD STRENGTH, ksi



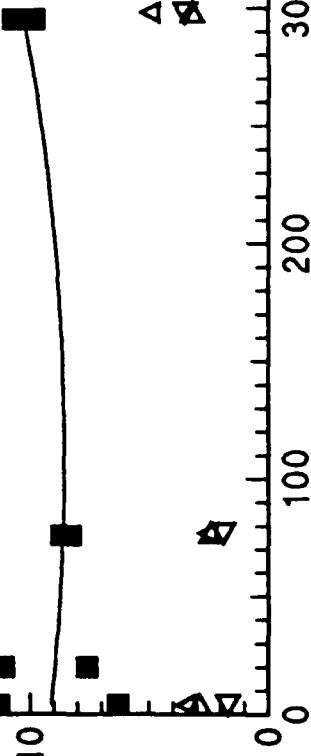
# WL049-T6

Product Form = Rolled Plate  
T Orientation

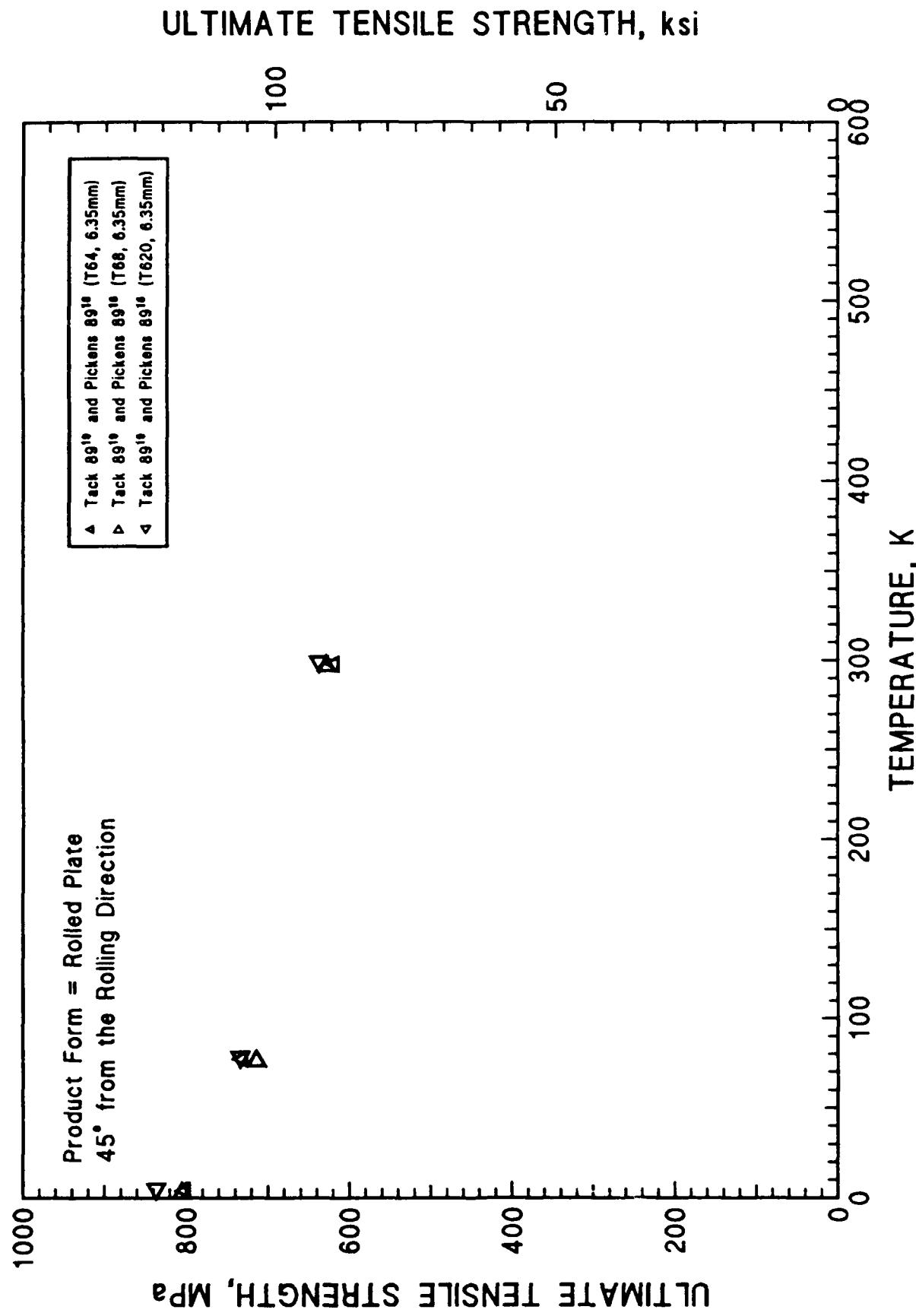
- Reed 90<sup>1</sup> (T651, 12.7mm)
- ▲ Tack 89<sup>10</sup> and Pickens 89<sup>10</sup> (T64, 6.35mm)
- △ Tack 89<sup>10</sup> and Pickens 89<sup>10</sup> (T68, 6.35mm)
- ◀ Tack 89<sup>10</sup> and Pickens 89<sup>10</sup> (T620, 6.35mm)

ELONGATION, percent

40  
30

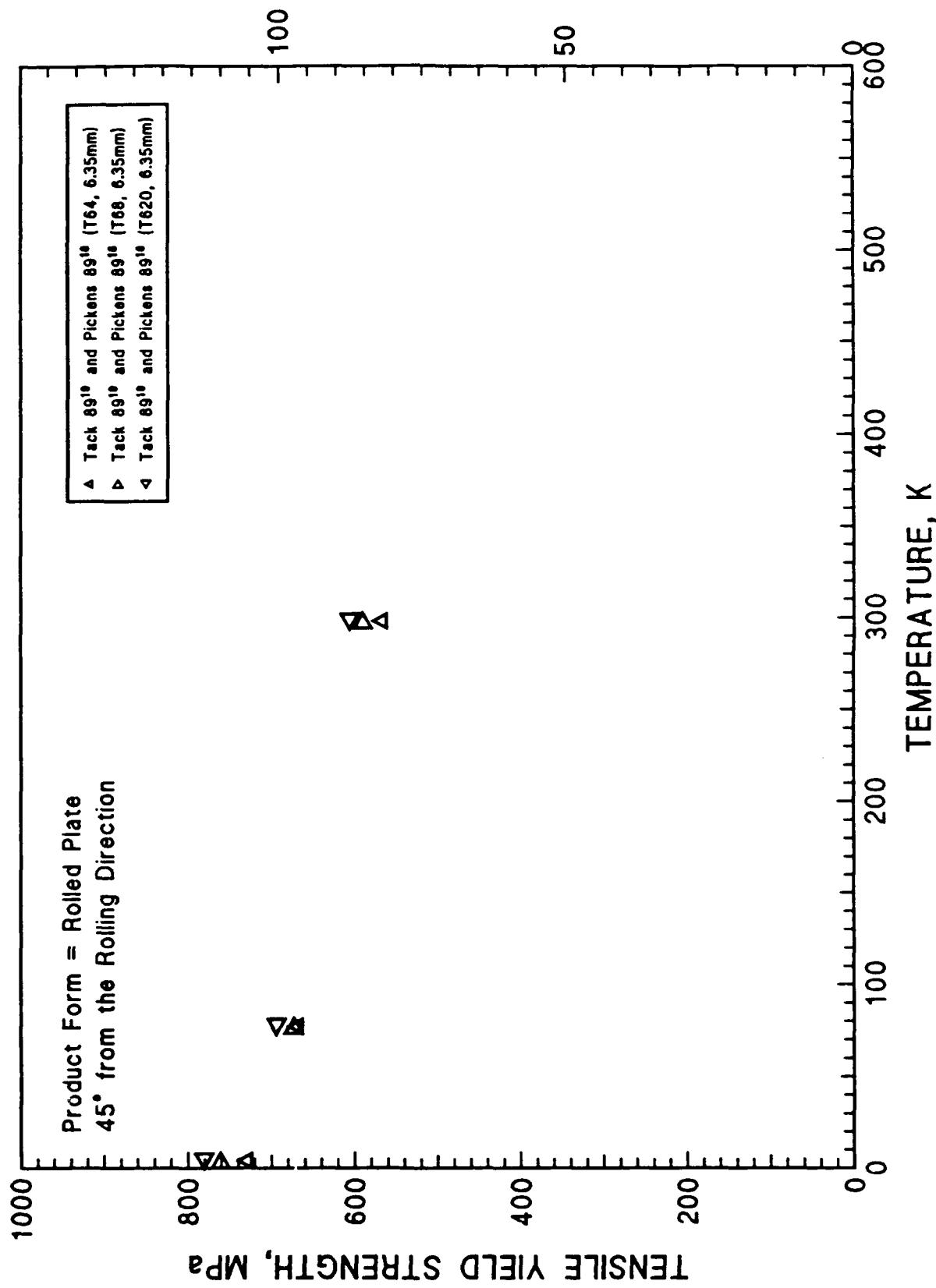


# WL049-T6



WL049-T6

### TENSILE YIELD STRENGTH, ksi



WL049-T6

Product Form = Rolled Plate  
45° from the Rolling Direction

- ▲ Tack 89<sup>18</sup> and Pickens 89<sup>18</sup> (T84, 0.35mm)
- △ Tack 89<sup>18</sup> and Pickens 89<sup>18</sup> (T88, 0.35mm)
- ▽ Tack 89<sup>18</sup> and Pickens 89<sup>18</sup> (T820, 0.35mm)

ELONGATION, PERCENT

30

20

10

40

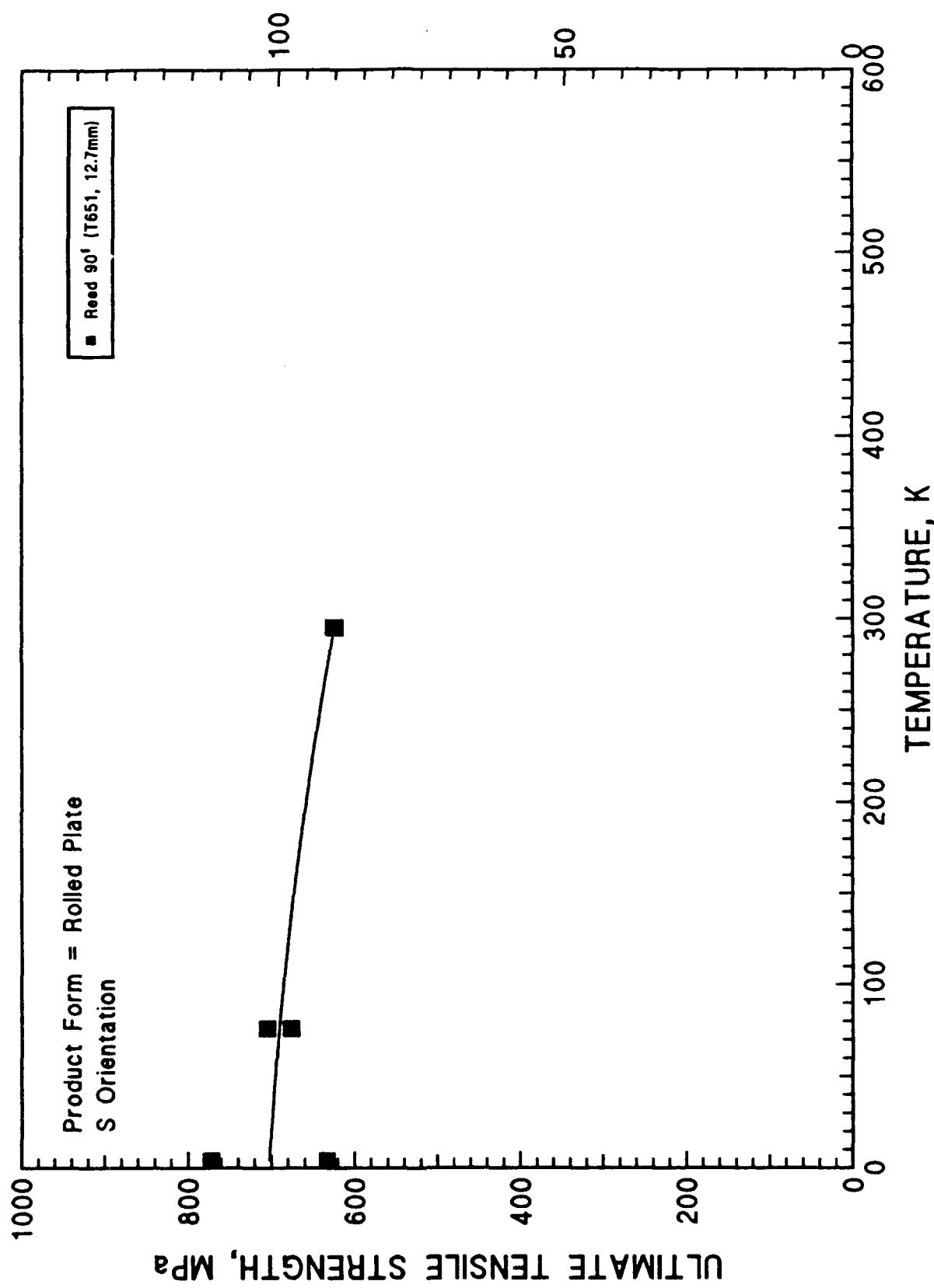
0

600  
500  
400  
300  
200  
100  
0

TEMPERATURE, K

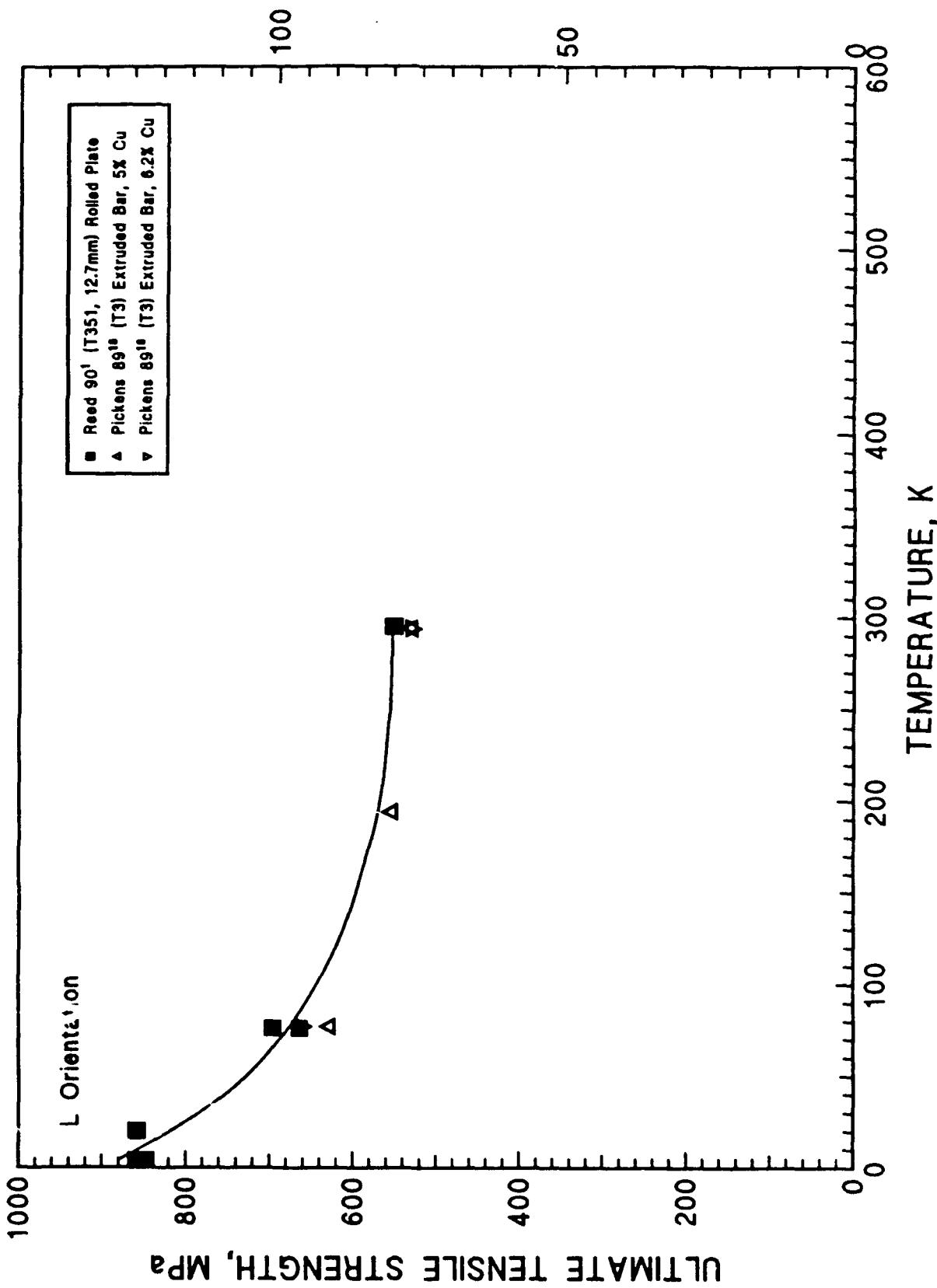
WL049-T6

ULTIMATE TENSILE STRENGTH, ksi



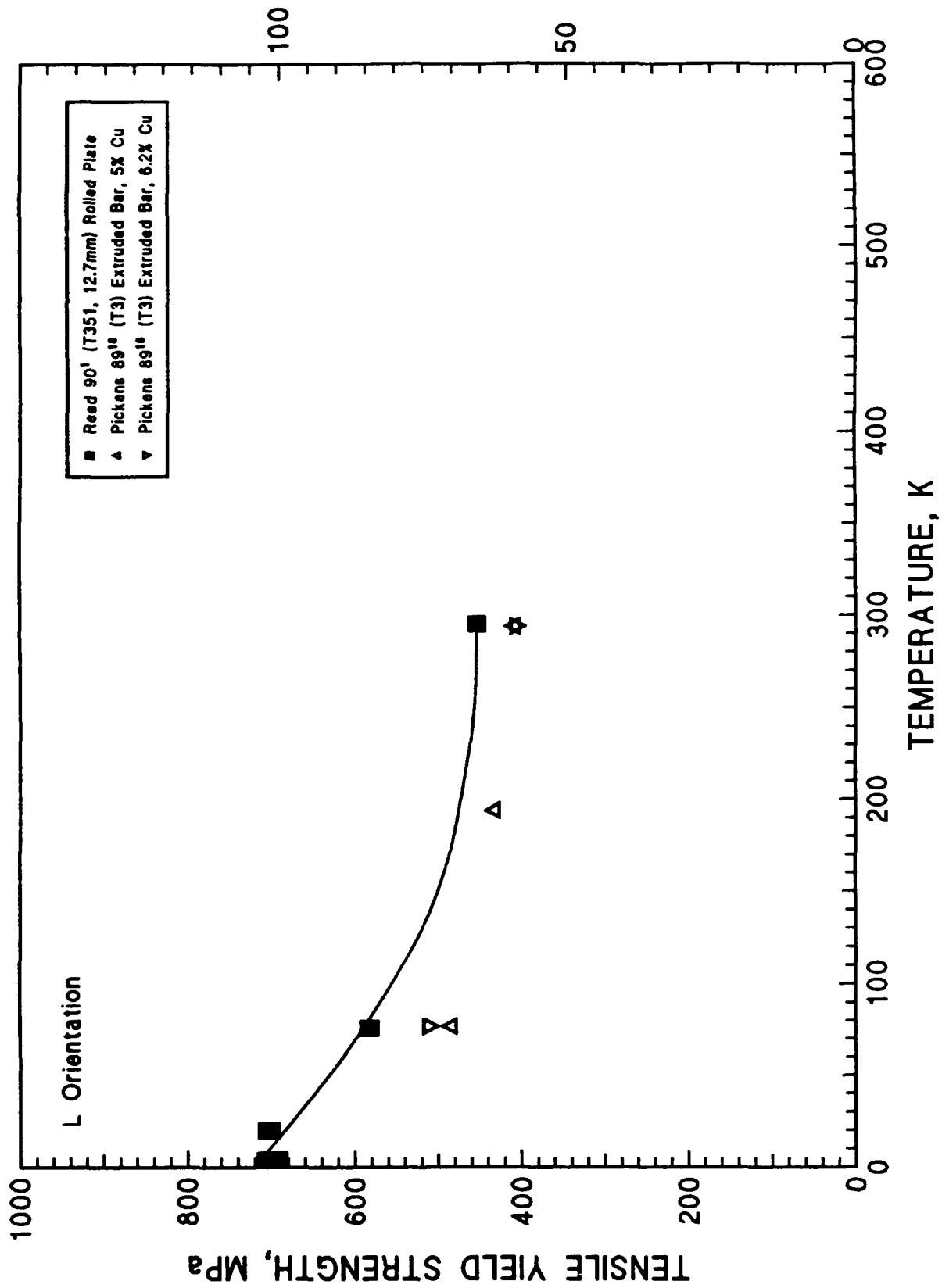
# WL049-T3

## ULTIMATE TENSILE STRENGTH, ksi

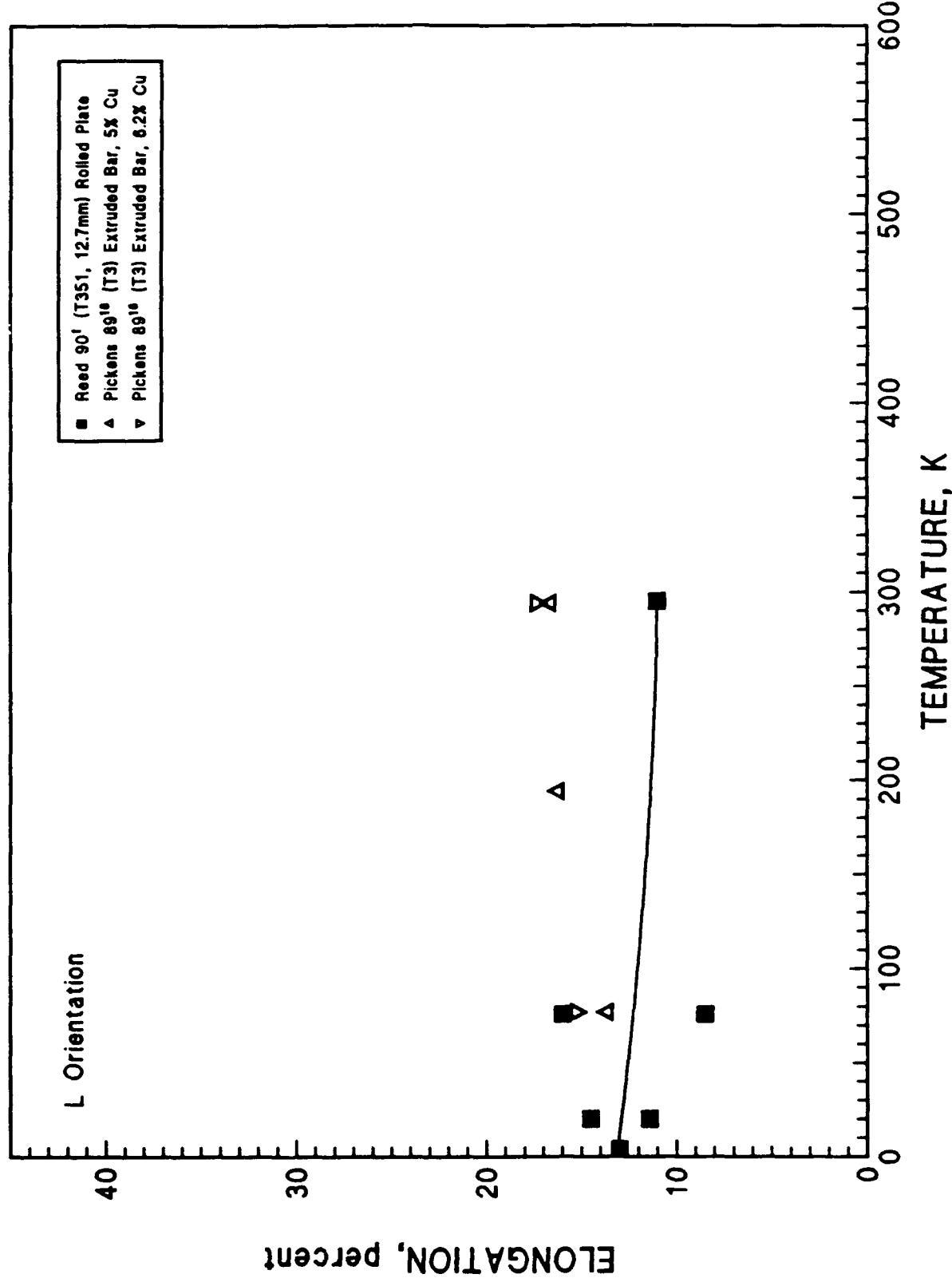


# WL049-T3

## TENSILE YIELD STRENGTH, ksi

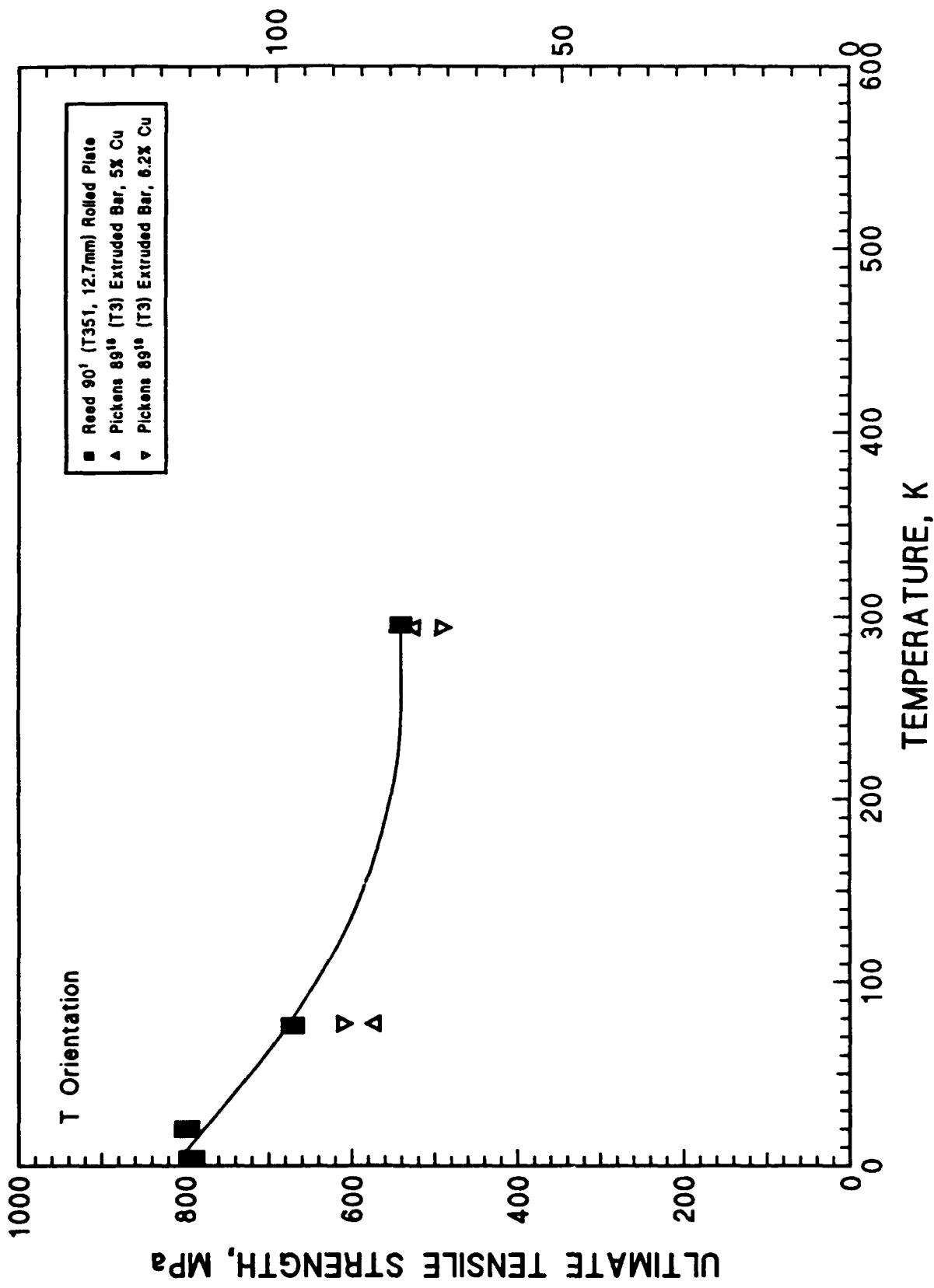


# WL049-T3



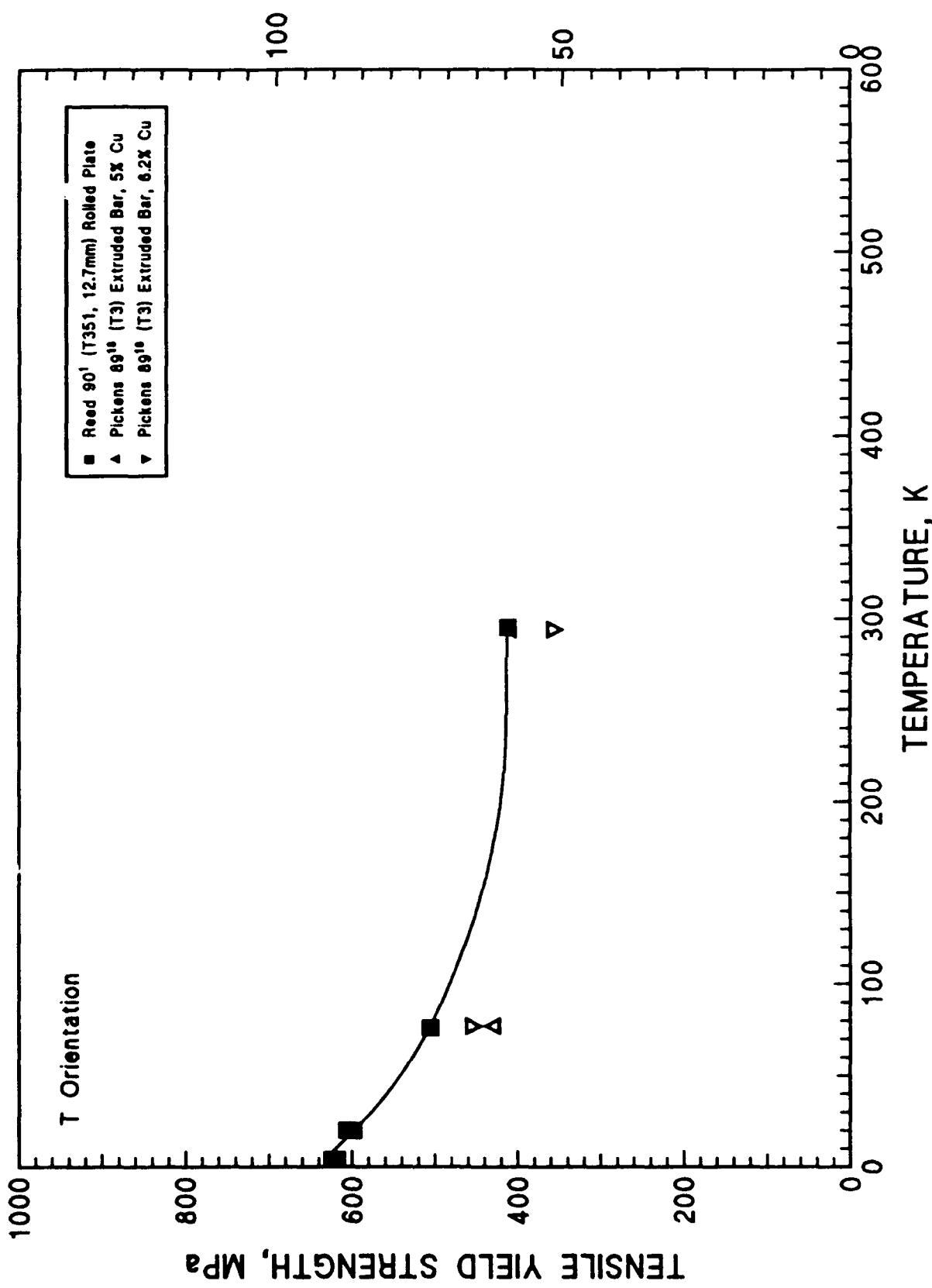
WL049-T3

ULTIMATE TENSILE STRENGTH, ksi

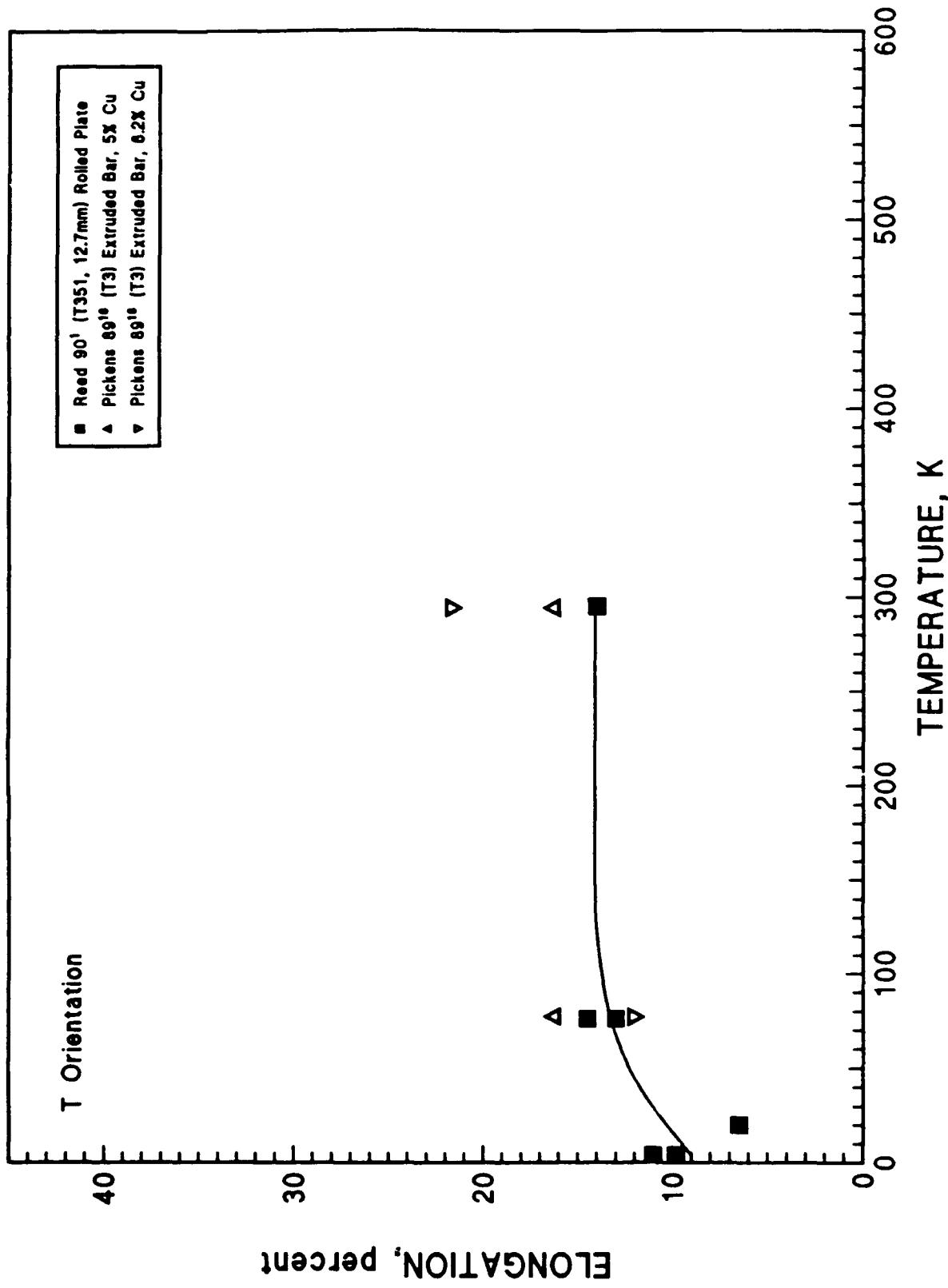


# WL049-T3

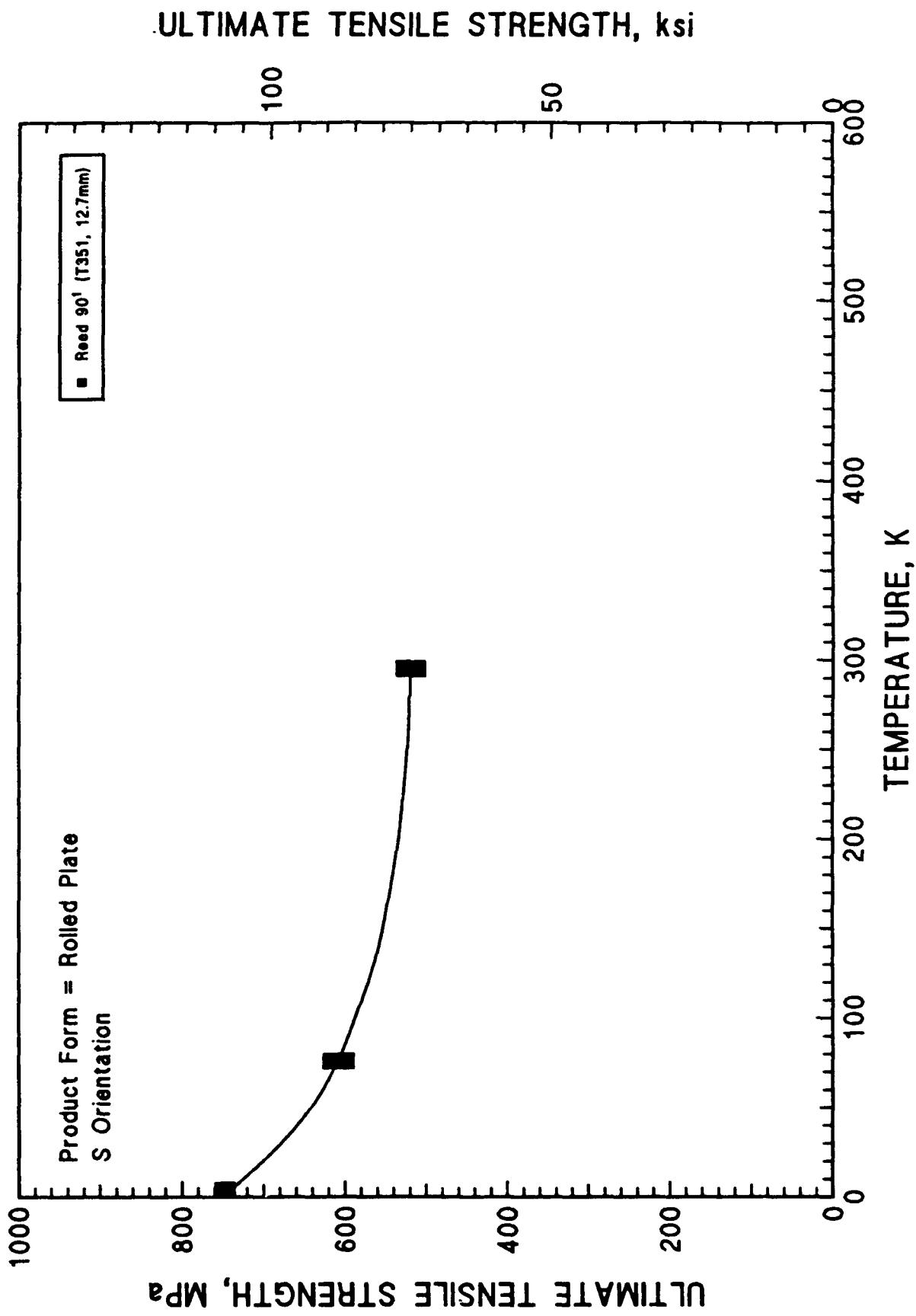
## TENSILE YIELD STRENGTH, ksi



# WL049-T3



WL049-T3



## Al-Li ALLOY WL049

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. L	Product Form	Thickness mm	Temp. °C	Time h	Stretch Z	Quench Cond.	SoIn. Treat.	Grain Size µm	Hardness	No. of Tests/ Data Pt	
1J	295	630.	606.	11.1	21.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	295	643.	606.	9.71	20.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	76	780.	712.	10.6	15.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	76	784.	712.	10.9	14.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	20	887.	772.	10.9	11.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	20	876.	776.	10.5	15.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	4	885.	783.	12.2	14.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	4	892.	787.	10.9	12.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	295	648.	615.	10.	23.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	295	641.	616.	10.	24.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	76	784.	717.	9.	17.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	76	780.	717.	7.	7.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	4	884.	784.	11.	14.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	4	881.	776.	10.	10.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
10A	294	727.	714.	6.3	MA	L	T8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	1
10A	77	840.	783.	7.6	MA	L	T8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	1
20B	593	NA	150.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
20B	593	NA	150.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. L	Temper T8	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Soln. Treat. Temp. °C	Quench h	Cond. %	Grain Size μm	Hardness	No. of Tests/ Data Pt
20B	538	NA	300.	NA	NA	L	T8	NA	NA	NA	3	NA	NA	NA	NA	NA	NA	NA
20B	465	NA	485.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20B	450	NA	536.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20B	425	NA	600.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20B	366	NA	665.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20B	283	NA	676.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20B	77	NA	847.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20B	20	NA	847.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
18A	294	658.	618.	10.3	NA	L	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	3	NA	NA	NA
18A	164	676.	636.	6.	NA	L	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18A	77	755.	676.	9.1	NA	L	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
16B	284	657.	633.	6.4	NA	L	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
16B	77	705.	701.	9.8	NA	L	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
14	295	637.	569.	5	17.0	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
14	285	629.	565.	6.7	15.5	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
14	76	766.	675.	7.2	11.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
14	76	760.	667.	6.6	13.3	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
14	20	873.	736.	9.35	11.8	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
14	20	873.	736.	10.5	11.	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Elong. %	R.A. %	Orient. z	Temper L	Product Form	Thickness mm	Temp. °C	Time h	Stretch %	Quench Cond.	Grain Size μm	Hardness Hv	No. of Tests/ Data Pt
14	4	669.	736.	7.55	11.	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	1
14	4	673.	748.	8.35	11.8	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	1
16B	4	695.	631.	5.2	NA	L	T6	Rolled Plate	6.35	160	6.	NA	504	1.	3
16B	4	916.	655.	4.2	NA	L	T6	Rolled Plate	6.35	160	20.	NA	504	1.	3
16B	4	660.	706.	4.	NA	L	T6	Rolled Plate	6.35	160	4.	NA	504	1.	3
18A	298	696.	670.	4.3	NA	L	T6	Rolled Plate	6.35	160	20.	NA	504	1.	3
18A	298	684.	641.	5.1	NA	L	T6	Rolled Plate	6.35	160	4.	NA	504	1.	3
18A	298	681.	645.	5.8	NA	L	T6	Rolled Plate	6.35	160	6.	NA	504	1.	3
18A	77	796.	758.	5.4	NA	L	T6	Rolled Plate	6.35	160	8.	NA	504	1.	3
18A	77	804.	784.	3.6	NA	L	T6	Rolled Plate	6.35	160	8.	NA	504	1.	3
18A	77	794.	745.	4.7	NA	L	T6	Rolled Plate	6.35	160	4.	NA	504	1.	3
20A	293	563.	398.	16.3	NA	L	T4	Extrusion	9.5	NA	1300.	0	504	0.6	1
20A	77	734.	552.	13.6	NA	L	T4	Extrusion	9.5	NA	4300.	0	504	0.6	1
10	295	552.	454.	NA	NA	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	1
10	295	550.	452.	9.65	10.9	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	1
10	76	696.	581.	11.6	13.9	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	1
10	76	664.	584.	8.5	13.2	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	1
10	20	659.	700.	11.4	11.7	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	1
10	20	659.	706.	14.5	11.	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	1

\*See Clements

Ref & Note	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A.	Orient.	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Soln. Treat. Z	Stretch Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests / Data Pt.
10 4 647.	708.	13.	14.7	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
10 4 659.	691.	13.	15.3	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18A 294 329.	407.	16.6	MA	L	T3	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18A 194 353.	431.	16.2	MA	L	T3	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18A 77 627.	483.	13.6	MA	L	T3	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18G 294 331.	407.	17.4	MA	L	T3	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18G 77 663.	512.	15.3	MA	L	T3	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18A 294 487.	330.	21.5	MA	L	Rev	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18A 194 434.	315.	19.	MA	L	Rev	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
18A 77 577.	404.	25.2	MA	L	Rev	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J 295 638.	391.	10.6	20.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J 76 762.	682.	6.4	12.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J 76 760.	672.	9.1	12.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J 20 652.	720.	6.	9.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J 20 654.	730.	9.4	10.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J 4 663.	752.	8.7	12.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J 4 655.	736.	6.5	6.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1L 295 637.	592.	11.	27.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. I	Temper T	Product Form	Thickness mm	Temp. °C	Time h	Stretch I	Soln. Treat. Temp. °C Time h Cond.	Quench Temp. °C Time h Cond.	Grain Size μm	Hardness Data Pt	No. of Tests/ Data Pt
1L 285	630.	587.	10.	27.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L 76	755.	675.	6.	7.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L 76	765.	685.	9.	15.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L 4	846.	766.	6.	8.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L 4	860.	784.	9.	14.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
18C 284	658.	630.	3.9	MA	T	T8	Extruded Bar	9.53	NA	NA	NA	NA	NA	NA	NA	NA	1
18D 77	753.	705.	2.62	MA	T	T8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18D 284	607.	566.	9.8	MA	T	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18D 194	678.	636.	6.	MA	T	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18D 77	755.	576.	9.1	MA	T	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18H 284	612.	579.	2.4	MA	T	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
18H 77	693.	627.	7.1	MA	T	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 295	621.	543.	9.4	17.8	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 76	744.	639.	5.3	11.8	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 76	744.	635.	6.3	10.2	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 20	853.	720.	MA	MA	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 20	833.	707.	5.3	8.7	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 4	860.	726.	8.9	8.7	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Product Form	Pr-Jnt. Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Quench Cond.	Soln. Treat. Temp. °C	Grain Size μm	Hardness	No. of Tests/ Data Pt	
1H	4	842.	736.	NA	NA	T	T651 Oiled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
18E	4	867.	800.	3.3	NA	T	T6 Rolled Plate	6.35	180	4.	0	504	1.	WQ	NA	3	
18E	4	872.	854.	1.7	NA	T	T6 Rolled Plate	6.35	180	20.	0	504	1.	WQ	NA	3	
18E	4	859.	823.	2.9	NA	T	T6 Rolled Plate	6.35	180	6.	0	504	1.	WQ	NA	3	
19B	298	674.	651.	3.5	NA	T	T6 Rolled Plate	6.35	180	20.	0	504	1.	WQ	NA	3	
19B	298	654.	616.	4.8	NA	T	T6 Rolled Plate	6.35	180	4.	0	504	1.	WQ	NA	3	
19B	298	663.	634.	3.2	NA	T	T6 Rolled Plate	6.35	180	6.	0	504	1.	WQ	NA	3	
19B	77	775.	755.	1.9	NA	T	T6 Rolled Plate	6.35	180	20.	0	504	1.	WQ	NA	3	
19B	77	762.	752.	2.4	NA	T	T6 Rolled Plate	6.35	180	6.	0	504	1.	WQ	NA	3	
88	198	77	762.	752.	2.4	NA	T	T6 Rolled Plate	6.35	180	4.	0	504	1.	WQ	NA	3
10	285	544.	412.	10.	23.	T	T351 Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
10	285	538.	412.	14.	22.	T	T351 Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
10	76	667.	506.	13.	12.9	T	T351 Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
10	76	675.	565.	NA	NA	T	T351 Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
10	20	803.	806.	NA	13.2	T	T351 Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
10	4	787.	616.	9.8	15.	T	T351 Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
10	4	798.	624.	11.	16.3	T	T351 Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
18D	294	523.	408.	16.2	NA	T	T3 Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	1	

\*See Comments

Ref	Note	Temp.	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient.	Temper	Product Form	Thickness mm	Temp. °C	Time h	Stretch %	Temp. °C	Time h	Quench Cond.	Soln. Treat.	Grain Size μm	Hardness	No. of Tests/ Data Pt.
16D	77	571.	427.	16.2	NA	7	T	T3	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	
16G	294	493.	359.	21.7	NA	7	T	T3	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	
16G	77	612.	452.	12.1	NA	7	T	T3	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1J	295	562.	502.	16.	37.	45*	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J	295	559.	500.	14.	37.	45*	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J	76	657.	569.	15.	32.	45*	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J	76	673.	583.	17.	26.	45*	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
1J	4	765.	614.	19.	22.	45*	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
89	1J	4	746.	622.	16.	21.	45*	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	
16P	4	601.	729.	6.2	NA	45*	T6	Rolled Plate	6.35	180	4.	4	504	1.	wQ	NA	NA	NA	3	
16P	4	637.	761.	4.9	NA	45*	T6	Rolled Plate	6.35	180	20.	4	504	1.	wQ	NA	NA	NA	3	
16P	4	605.	761.	4.	NA	45*	T6	Rolled Plate	6.35	180	6.	4	504	1.	wQ	NA	NA	NA	3	
16C	298	616.	566.	9.4	NA	45*	T6	Rolled Plate	6.35	180	4.	4	504	1.	wQ	NA	NA	NA	3	
16C	298	637.	608.	6.4	NA	45*	T6	Rolled Plate	6.35	180	20.	4	504	1.	wQ	NA	NA	NA	3	
16C	298	620.	590.	6.5	NA	45*	T6	Rolled Plate	6.35	180	8.	4	504	1.	wQ	NA	NA	NA	3	
16C	77	714.	673.	4.2	NA	45*	T6	Rolled Plate	6.35	180	8.	4	504	1.	wQ	NA	NA	NA	3	
16C	77	734.	694.	4.0	NA	45*	T6	Rolled Plate	6.35	180	20.	4	504	1.	wQ	NA	NA	NA	3	
1K	295	604.	NA	NA	NA	S	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper S	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Quench Cond.	Soln. Treat. Time h	Grain Size μm	Hardness	Tests/ Data Pt.	No. of tests
1K	295	649.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1K	76	735.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1K	76	736.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1K	4	809.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	295	623.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	295	625.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	76	676.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	76	705.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	4	772.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	4	633.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1P	295	511.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1P	295	527.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1P	76	617.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1P	76	599.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1P	4	750.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1P	4	745.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

**TEST PARAMETERS**  
**Al-Li ALLOY ML049**

Ref & Note No.	Strain Rate 10 <sup>-4</sup> /s	Specimen			Supplier Prod.	Yr. No.	Lot No.	Product L(m) X W(m)	Major Elements					Minor Elements wt%					
		Type	Dia. mm	Thick mm					L1	Cu	Mo	Zr	Si	Fe					
1J	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Reynolds 1989	0367230A	1.22 X 1.22	0.38	4.7	0.4	0.12	0.02	0.03	0.37	NA	
1K	2.2	Round	2.5	NA	25.4	Random	5.	Reynolds 1989	0367230A	1.22 X 1.22	0.38	4.7	0.4	0.12	0.02	0.03	0.37	NA	
1L	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Reynolds 1990	9002311A	1.22 X 1.22	0.38	4.7	0.4	0.12	0.02	0.03	0.37	NA	
1M	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Reynolds 1989	0367240A	1.22 X 1.22	1.28	4.7	0.4	0.12	0.02	E-3	0.35	NA	
1N	2.2	Round	2.5	NA	25.4	Random	5.	Reynolds 1989	0367240A	1.22 X 1.22	1.28	4.7	0.4	0.12	0.02	0.03	0.35	NA	
1O	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Reynolds 1989	0367230A	1.22 X 1.22	1.28	4.7	0.4	0.12	0.02	0.03	0.35	NA	
1P	2.2	Round	2.5	NA	25.4	Random	5.	Reynolds 1989	0367230A	1.22 X 1.22	1.28	4.7	0.4	0.12	0.02	0.03	0.35	NA	
18A	4	Round	6.35	NA	25.4	Mid-plane	15.	H.M.	NA	0.102	1.3	5	0.4	0.14	NA	0.4	Ti: 0.03		
18B	1.67	Round	NA	NA	12.7	NA	NA	Reynolds	NA	NA	1.3*	5.4	0.4	0.14	NA	0.4	NA		
18C	4	Round	6.35	NA	25.4	Mid-plane	15.	H.M.	NA	NA	0.102	1.3	5	0.4	0.14	NA	0.4	Ti: 0.03	
18D	4	Round	6.35	NA	25.4	Mid-plane	15.	H.M.	NA	NA	0.051	1.3	5	0.4	0.14	NA	0.4	Ti: 0.03	
18E	1.67	Round	NA	NA	12.7	NA	NA	Reynolds	NA	NA	1.3*	5.4	0.4	0.14	NA	0.4	NA		
18F	1.67	Round	NA	NA	12.7	NA	NA	Reynolds	NA	NA	1.3*	5.4	0.4	0.14	NA	0.4	NA		
18G	4	Round	6.35	NA	25.4	Mid-plane	15.	H.M.	NA	NA	50.8	1.3	6.2	0.4	0.14	NA	0.4	Ti: 0.03	
18H	4	Round	6.35	NA	25.4	Mid-plane	15.	H.M.	NA	NA	50.8	1.3*	5.4	0.4	0.14	NA	0.4	Ti: 0.03	
18A	1.67	Round	NA	NA	12.7	NA	NA	Reynolds	NA	NA	1.3*	5.4	0.4	0.14	NA	0.4	NA		
18B	1.67	Round	NA	NA	12.7	NA	NA	Reynolds	NA	NA	1.3*	5.4	0.4	0.14	NA	0.4	NA		
18C	1.67	Round	NA	NA	12.7	NA	NA	Reynolds	NA	NA	1.3*	5.4	0.4	0.14	NA	0.4	NA		

Ref & Note	Strain Rate	Type	Specimen			Specimen Location	Time min	Supplier Prod.	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements					Minor Elements wt%	
			Dim	Thick	G.L.							Li	Cu	Mg	Zr	Si	Fe	
20A	10^-4/s	MA	MA	MA	MA	MA	NA	Reynolds	NA	NA	0.102	1.19	4.8	0.4	0.16	NA	NA	0.36 NA
20B	4	MA	MA	MA	MA	MA	NA	NA	NA	NA	NA	1.3	6.2	0.4	0.14	NA	NA	0.4 Ti: 0.03

Comments from the Al-Li Alloy WL049 Test Parameter Table

Reference and  
Note Number

18B--Reported composition is based on nominal values.

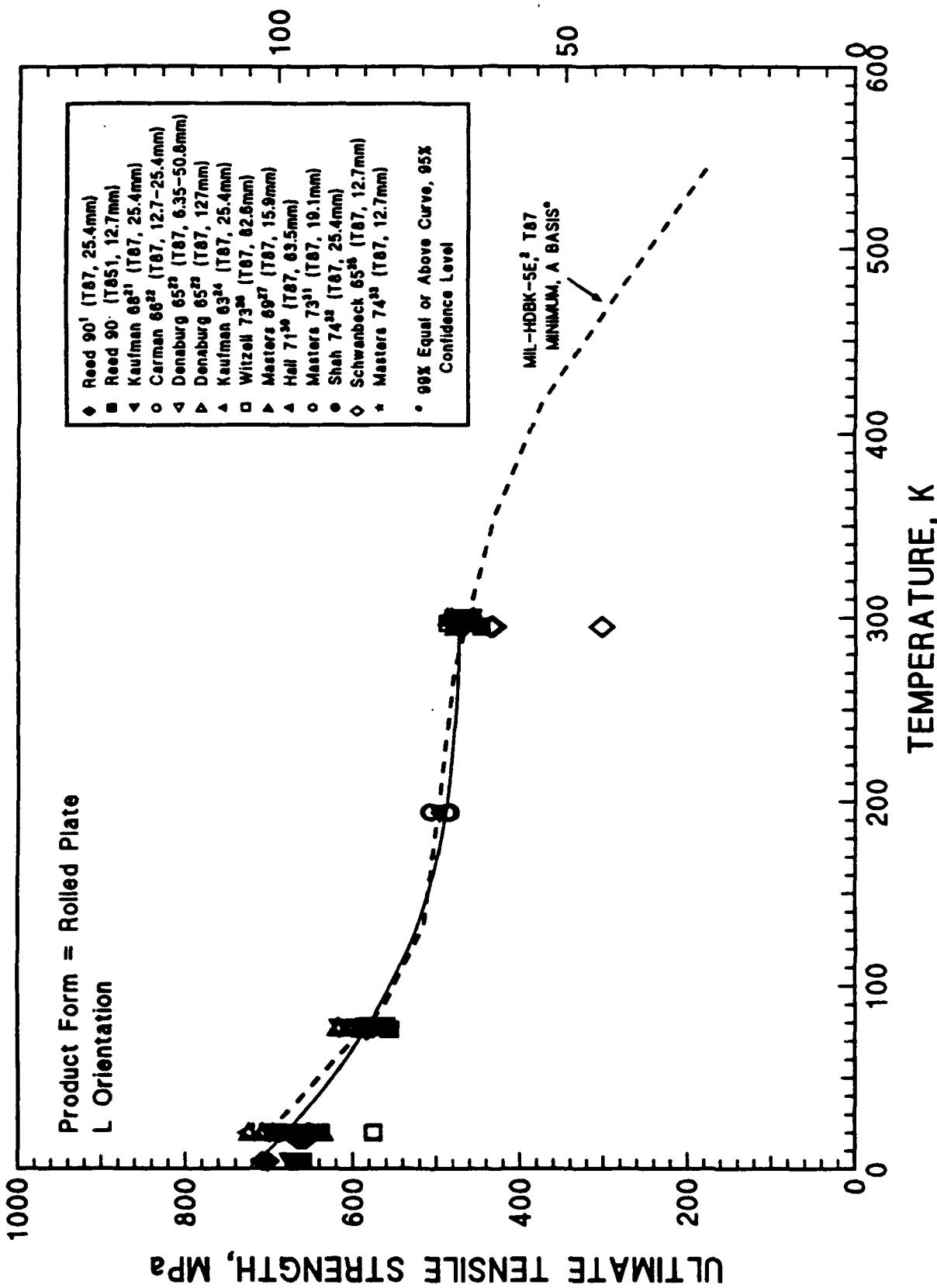
18E--Reported composition is based on nominal values.

18F--Reported composition is based on nominal values.

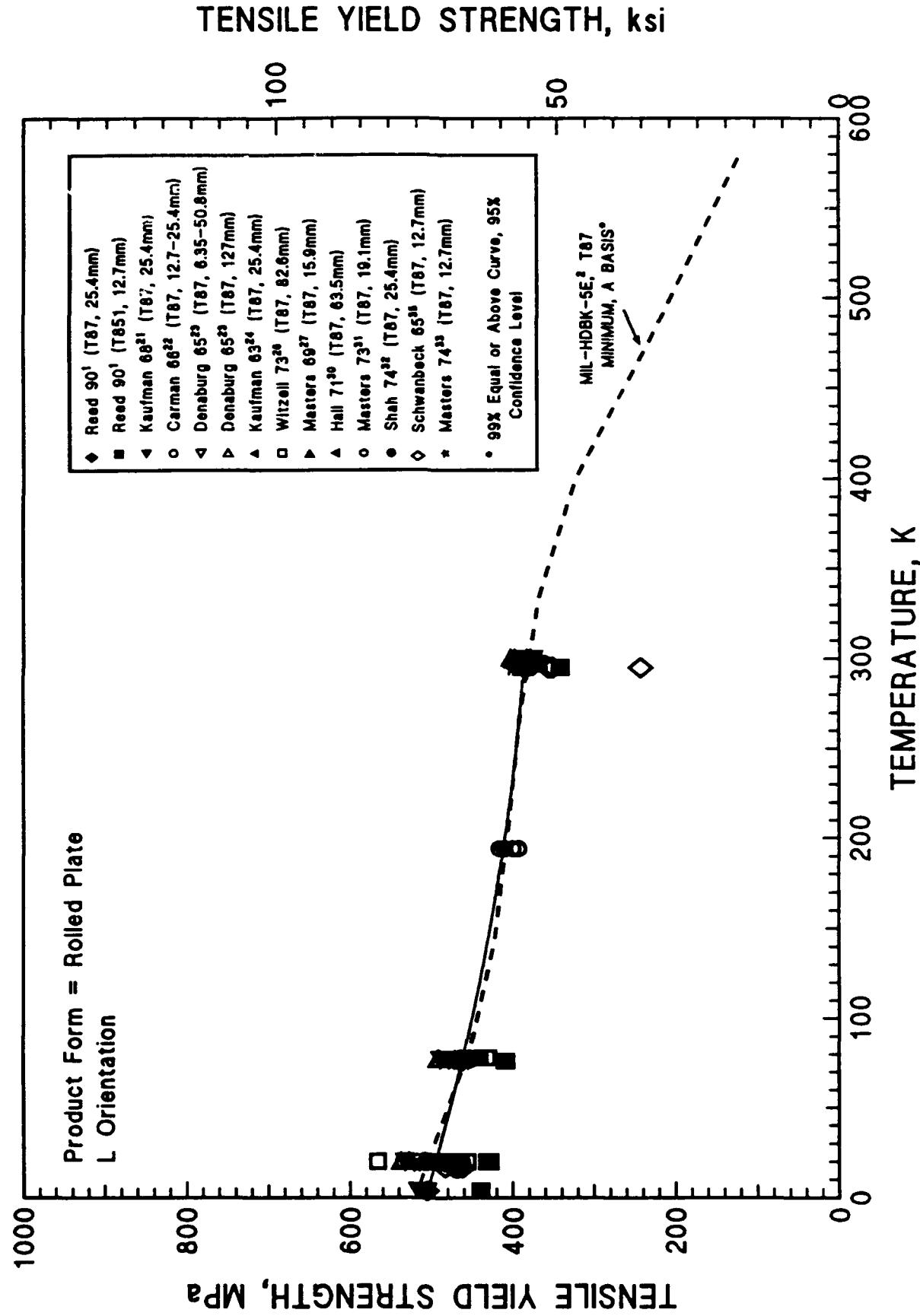
19A-C--Reported composition is based on nominal values.

2219-T8

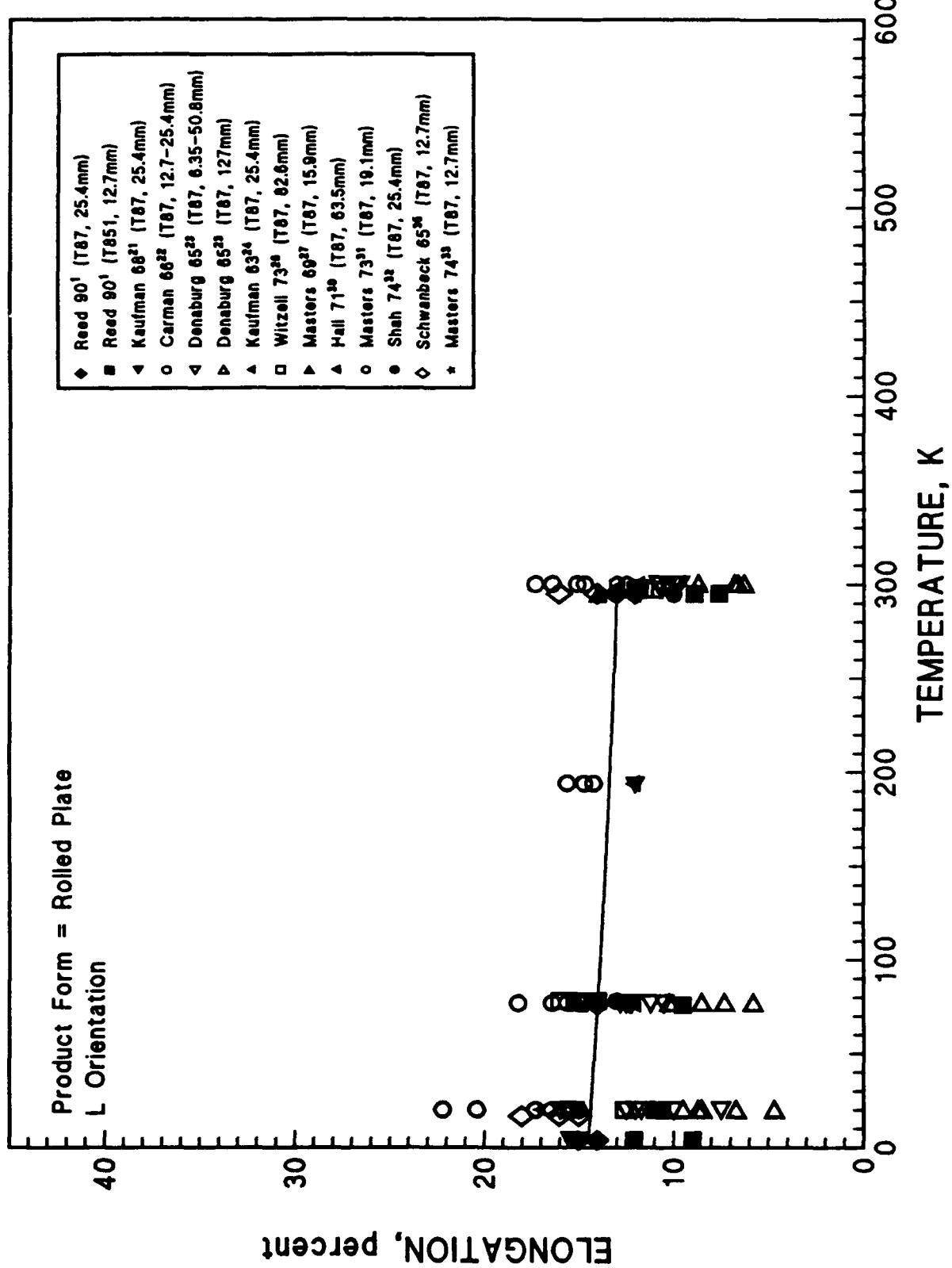
## **ULTIMATE TENSILE STRENGTH, ksi**



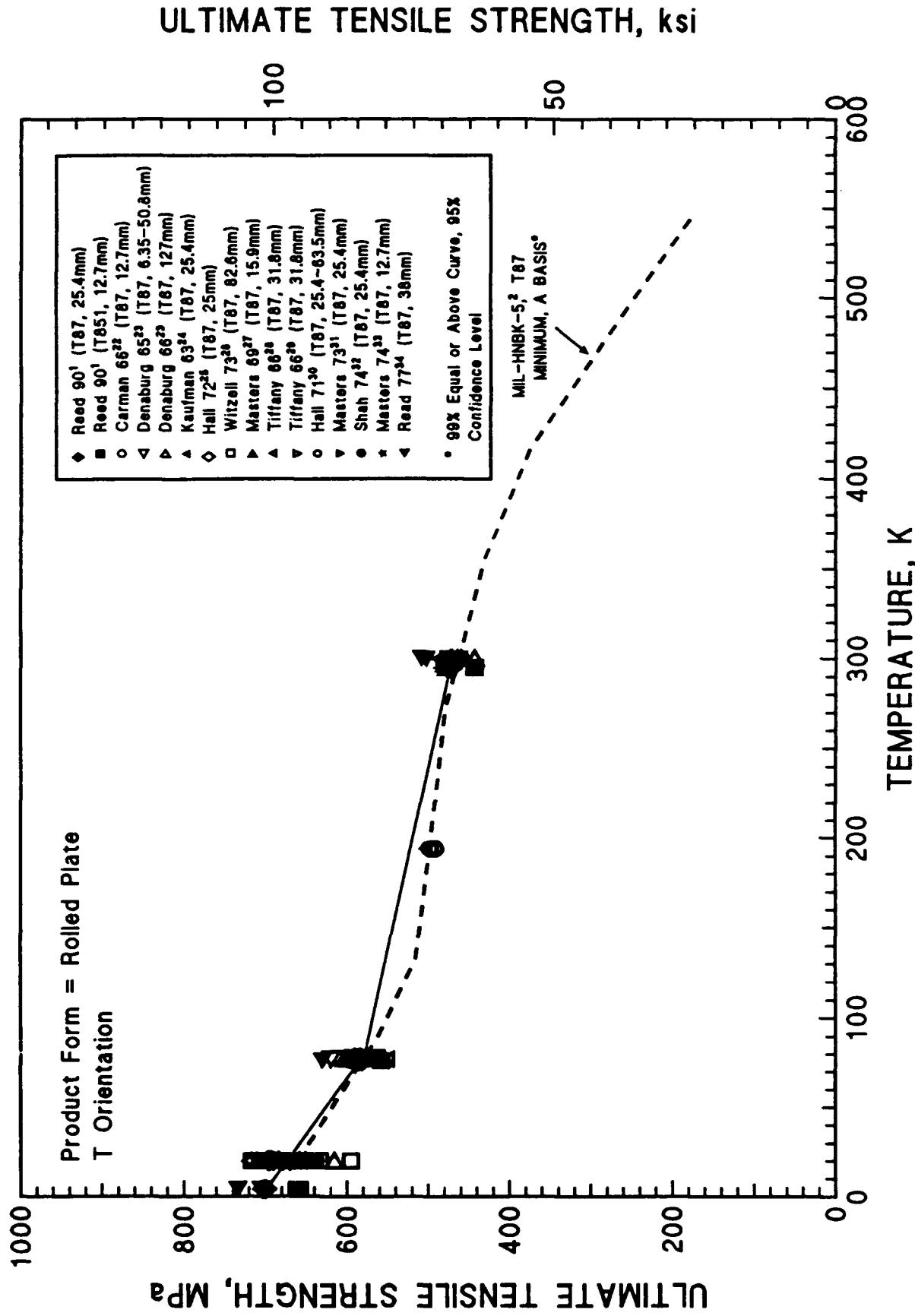
2219-T8



2219-T8

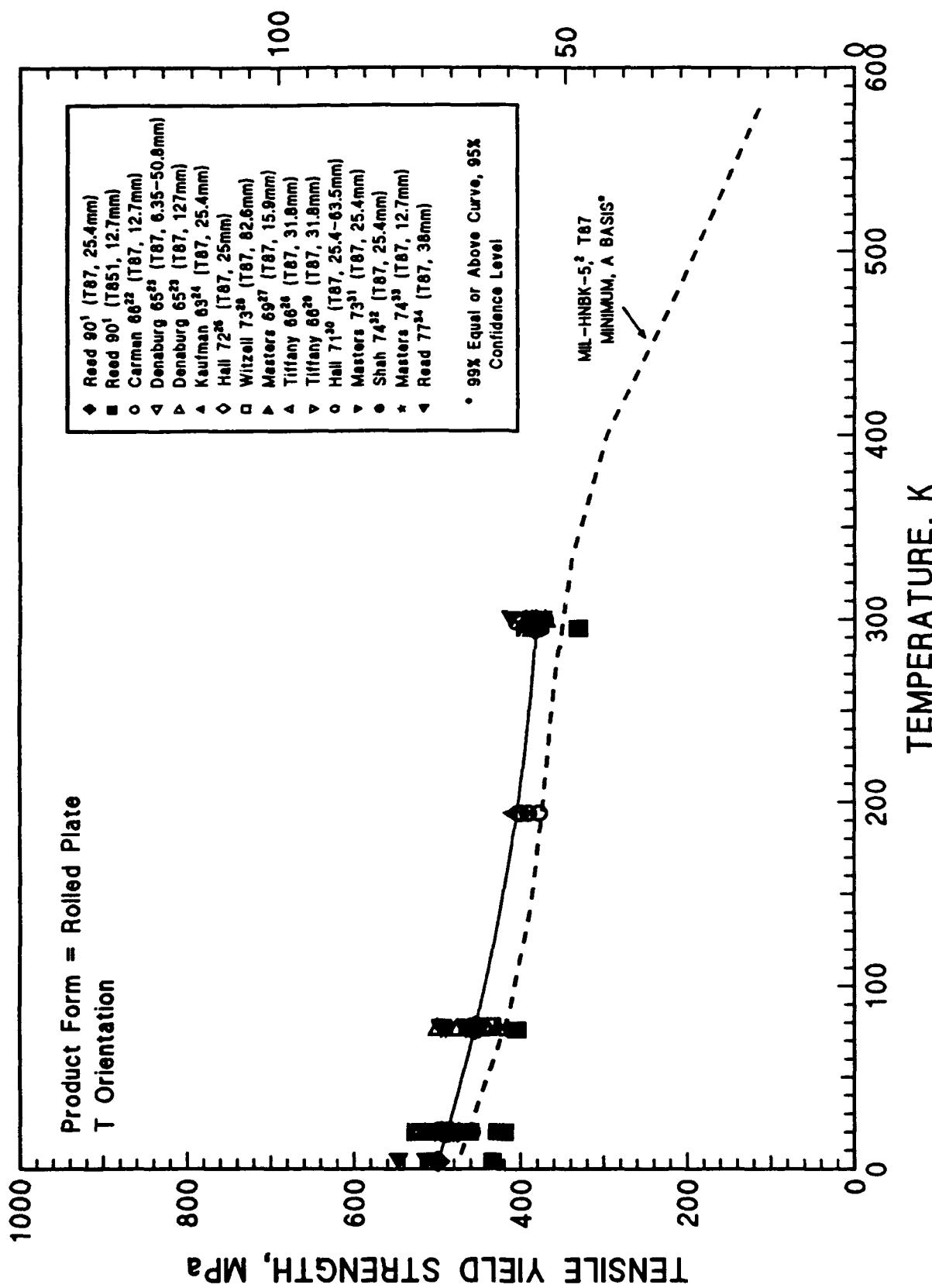


2219-T8

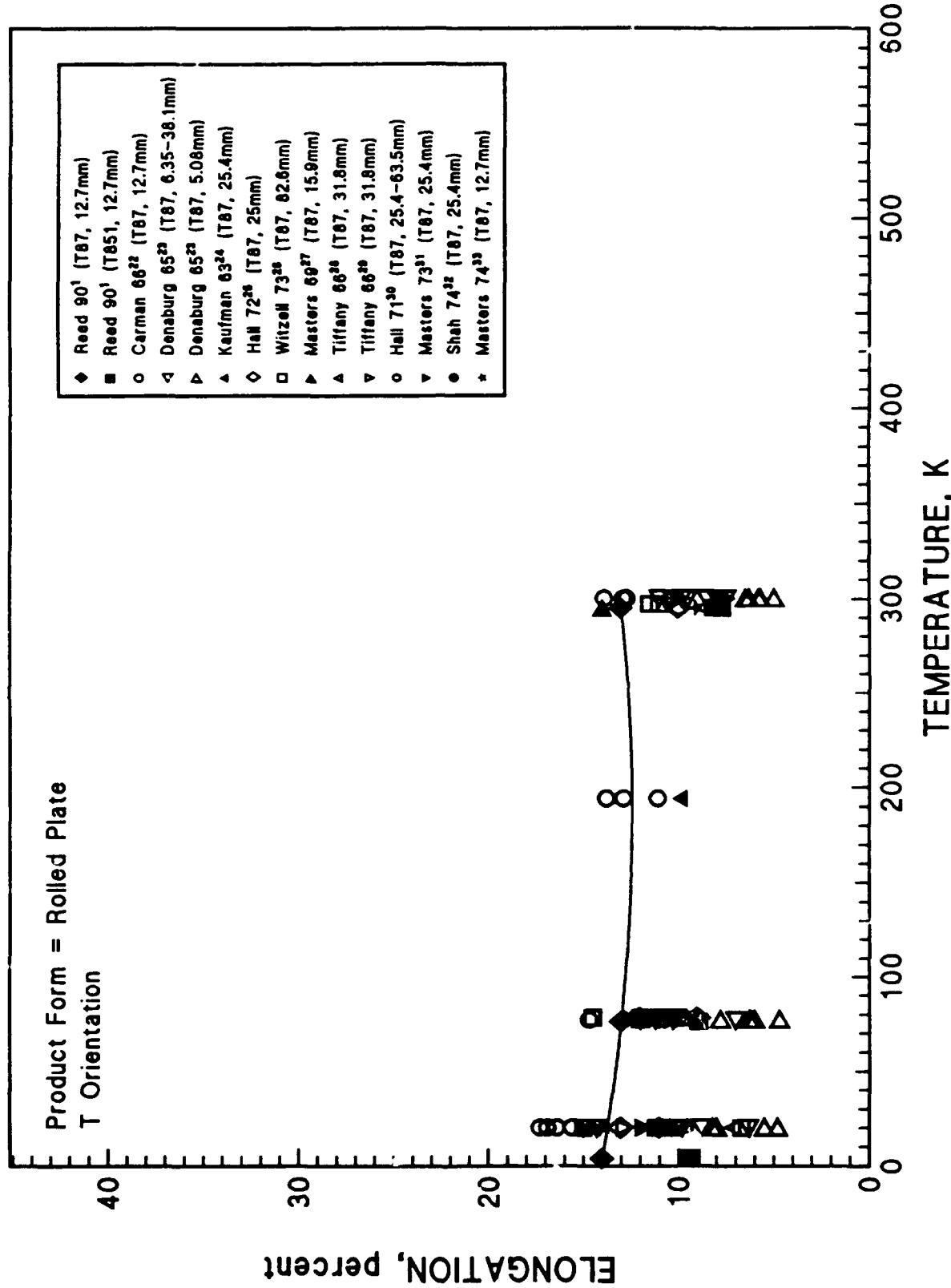


2219-T8

## TENSILE YIELD STRENGTH, ksi

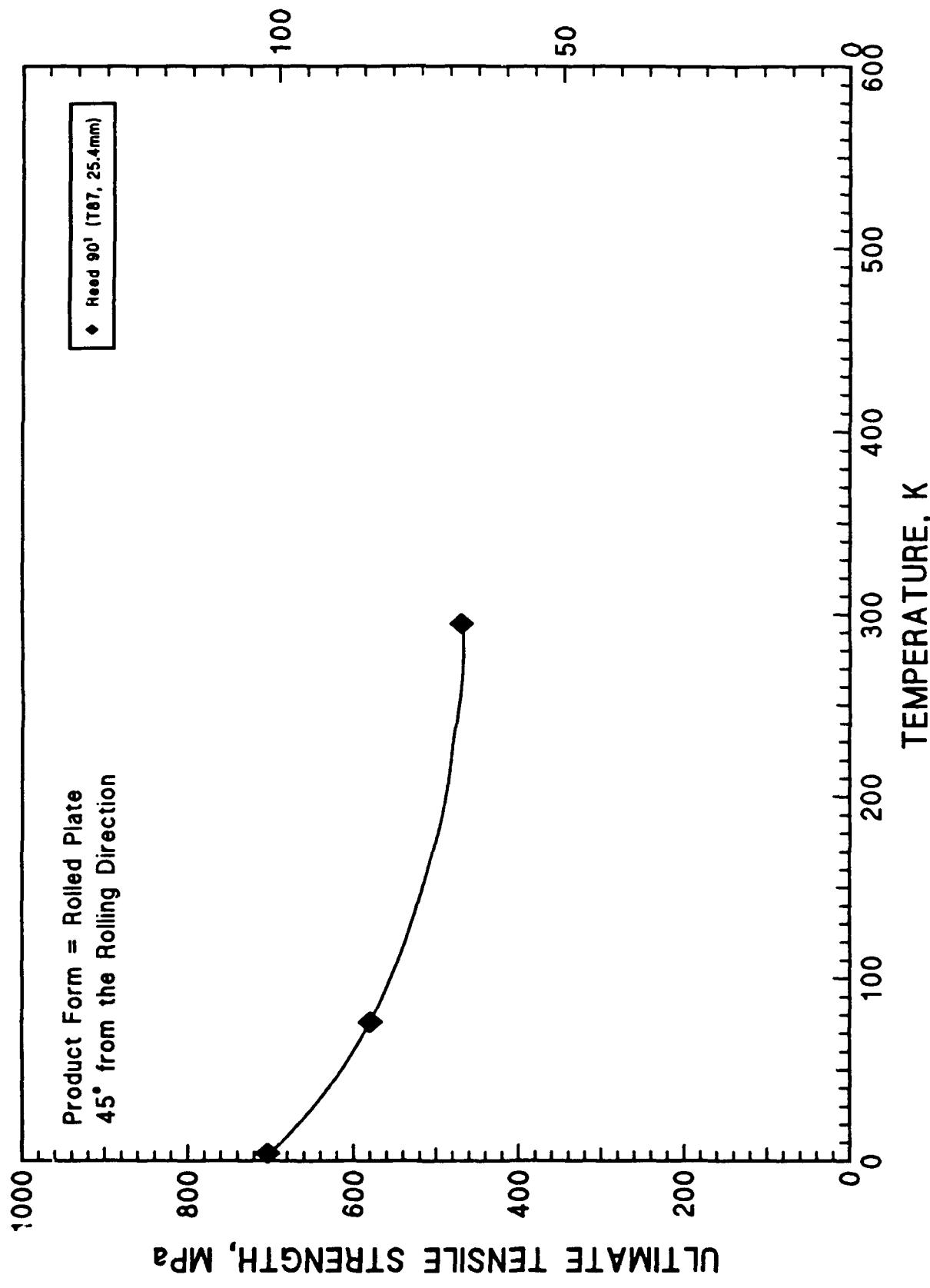


2219-T8

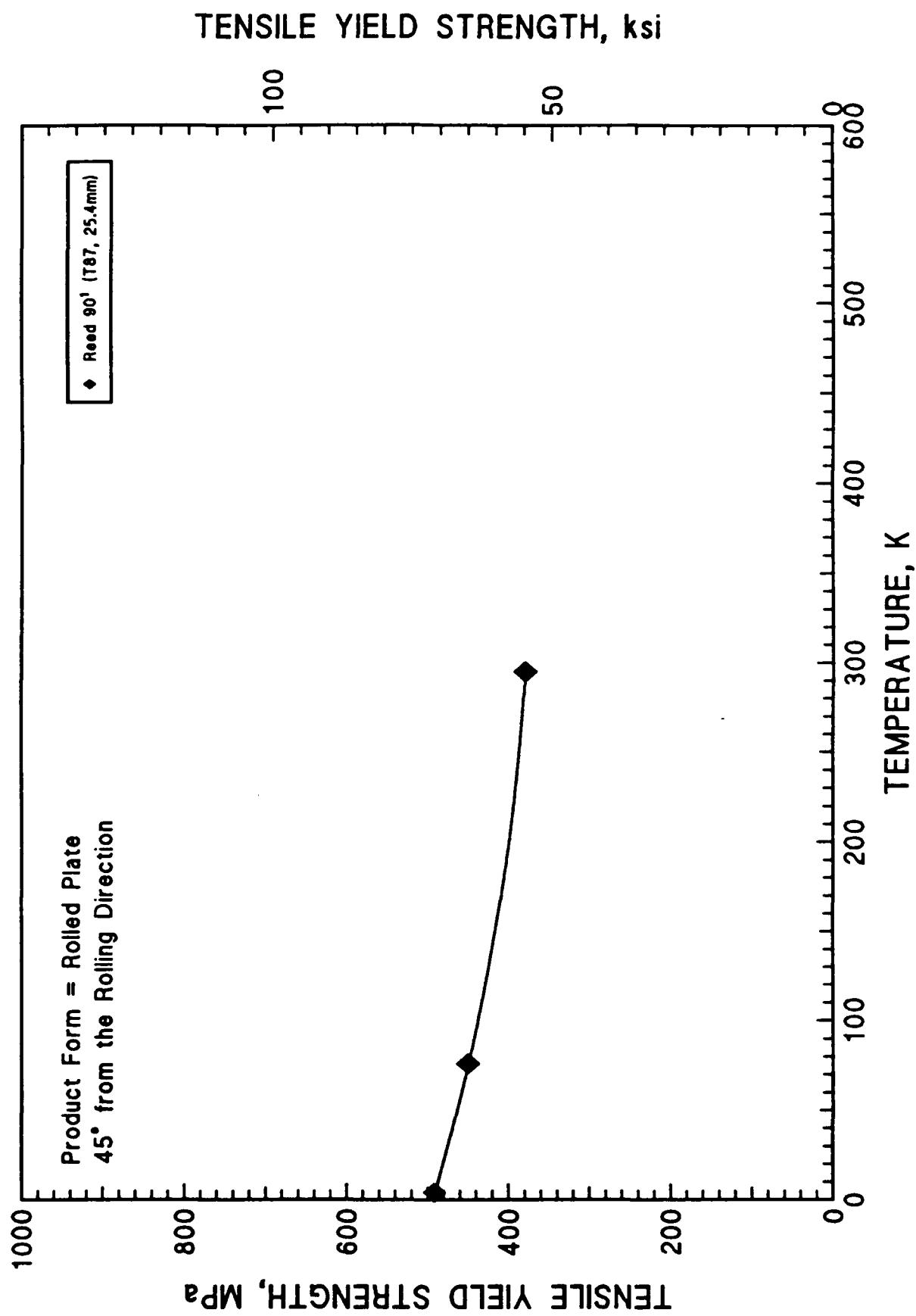


2219-T8

ULTIMATE TENSILE STRENGTH, ksi



2219-T8



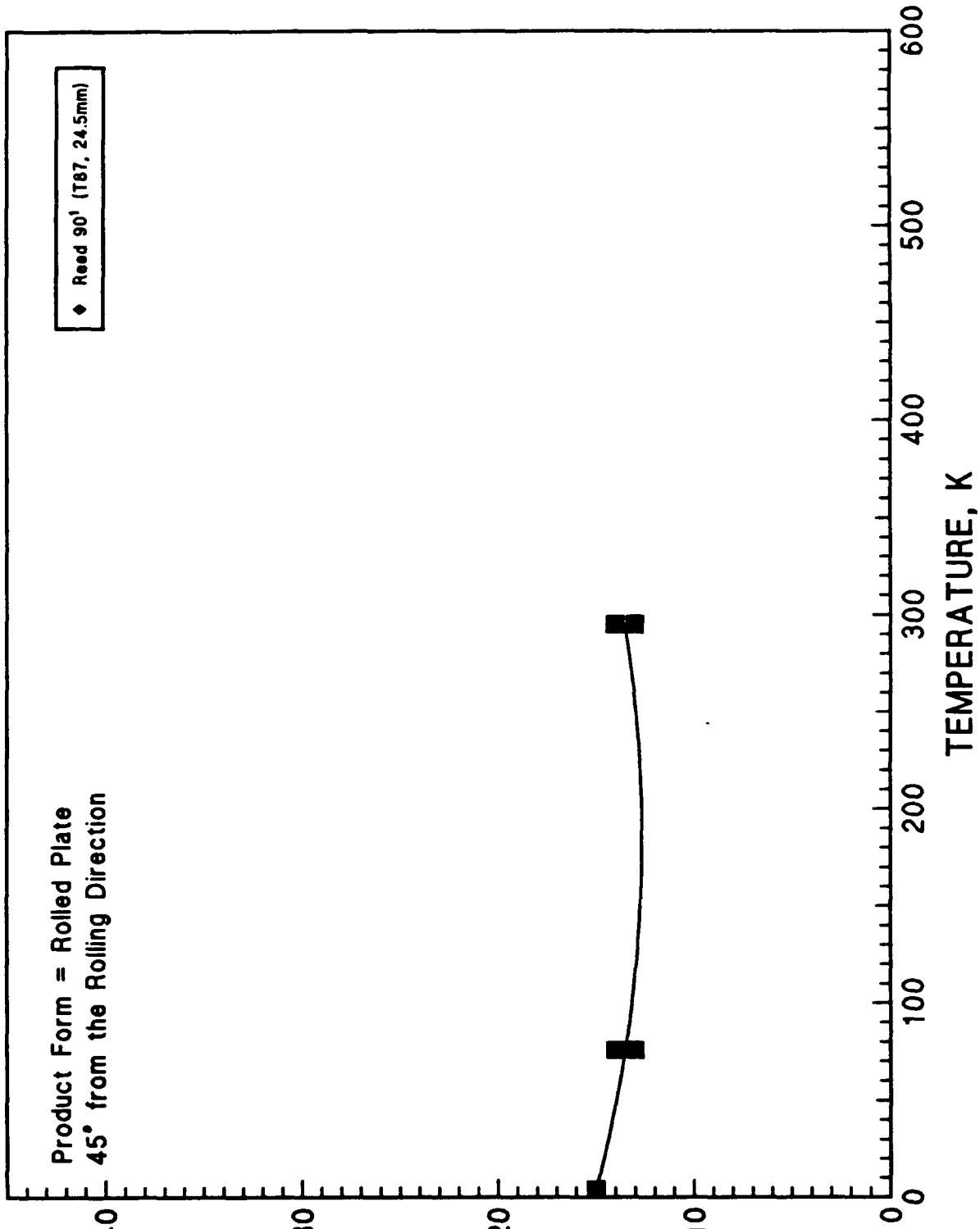
2219-T8

Product Form = Rolled Plate  
45° from the Rolling Direction

• Reed 90' (T87, 24.5mm)

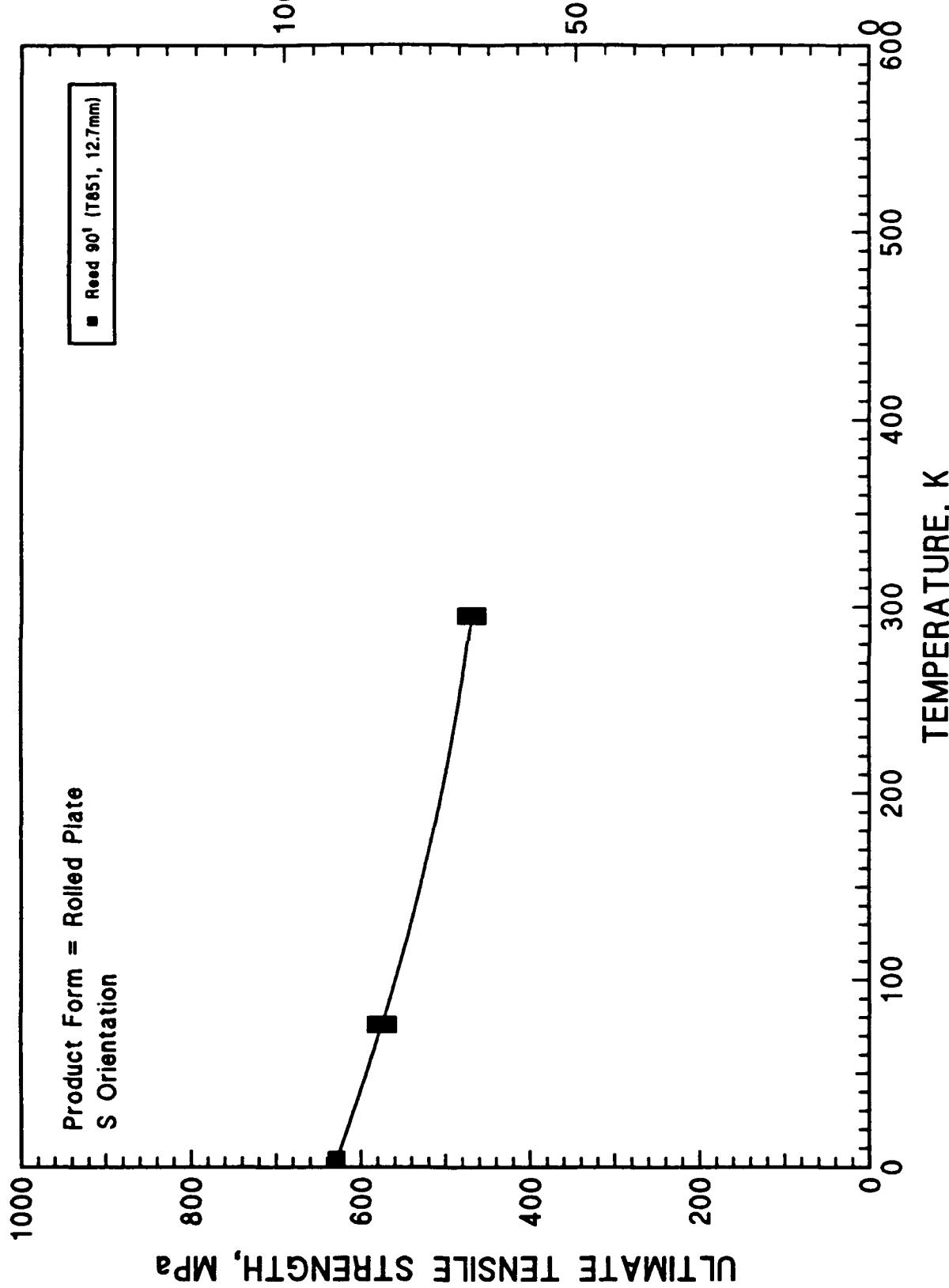
ELONGATION, PERCENT

102



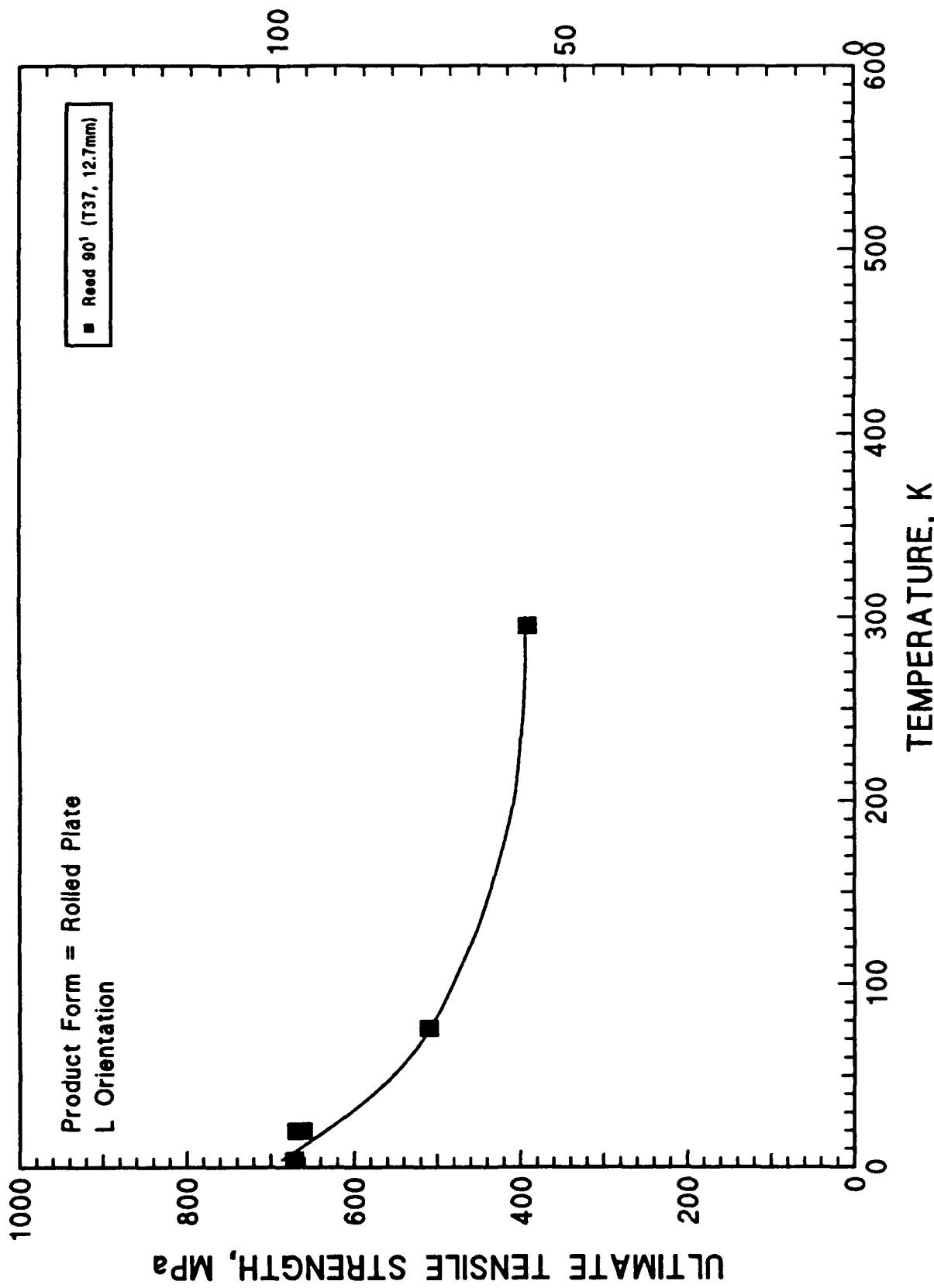
2219-T8

ULTIMATE TENSILE STRENGTH, ksi

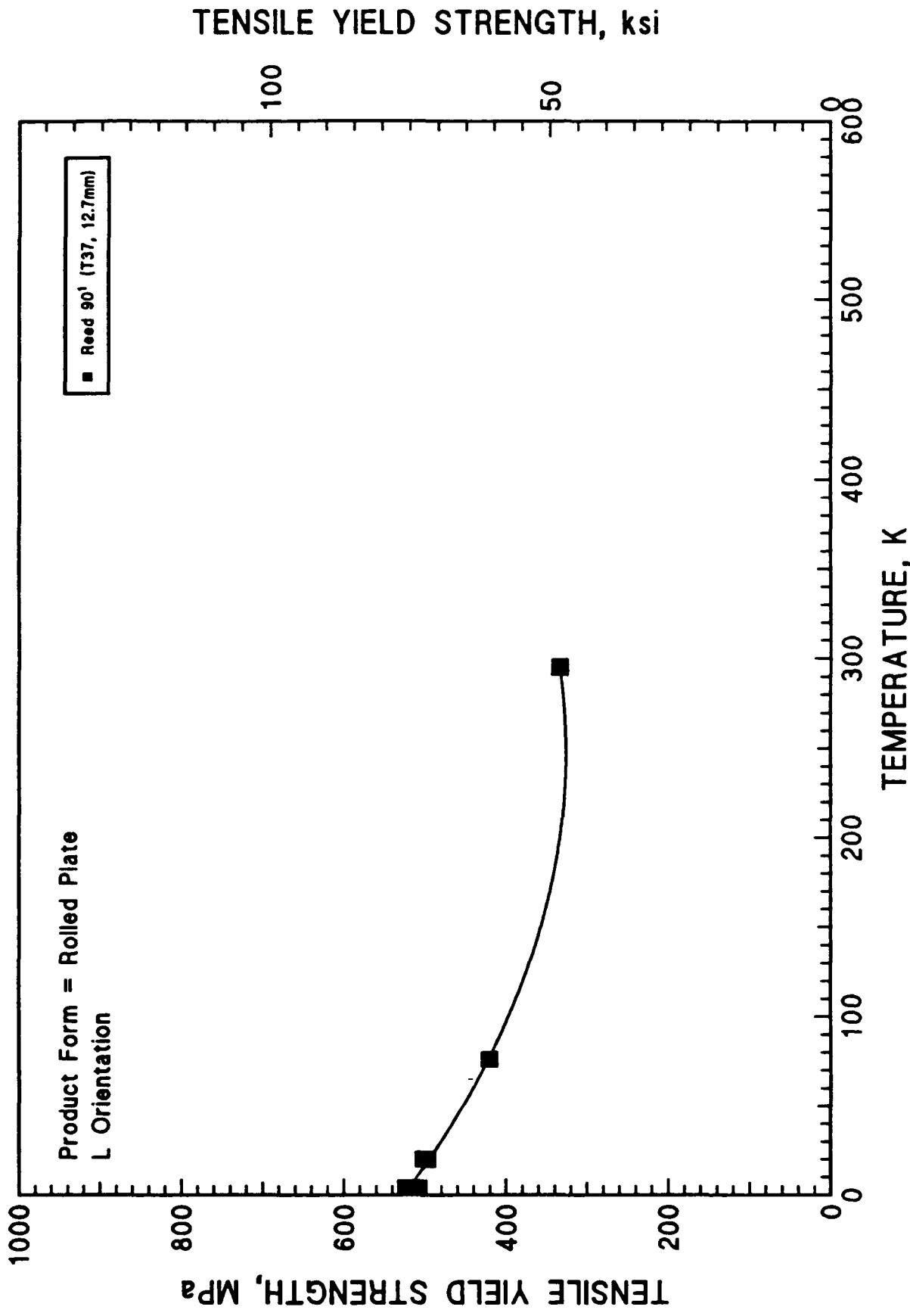


2219-T3

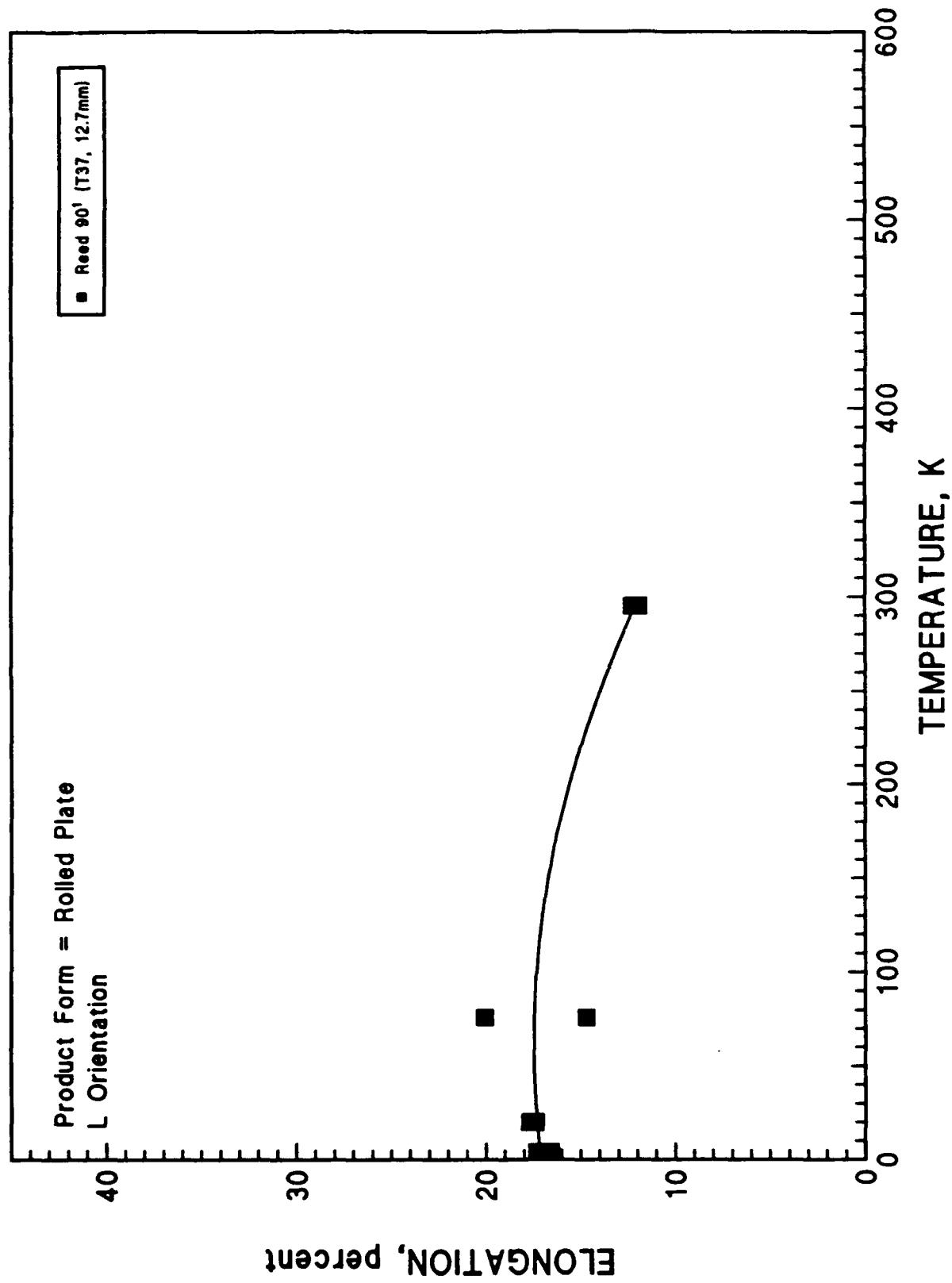
### ULTIMATE TENSILE STRENGTH, ksi



2219-T3

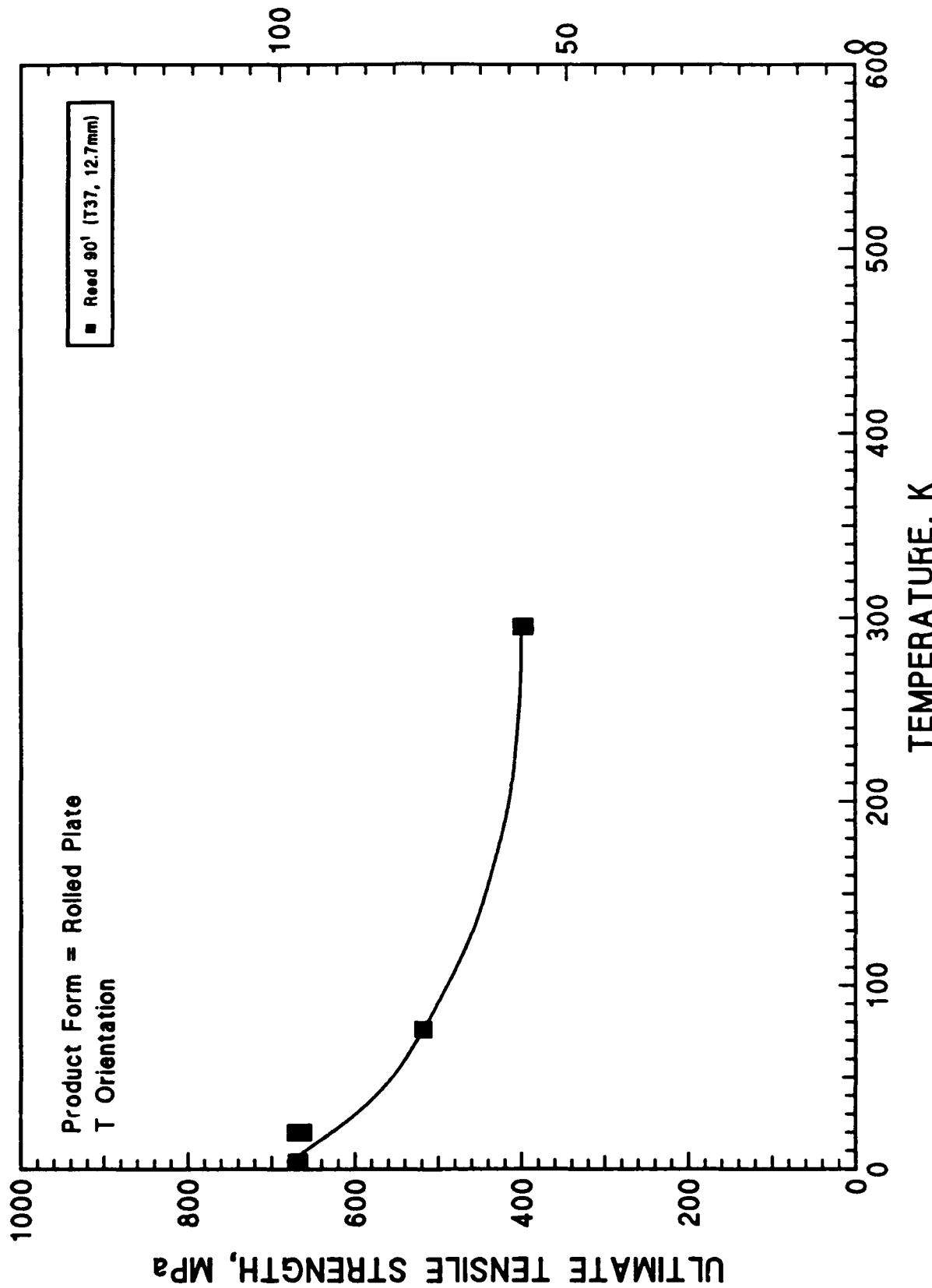


2219-T3

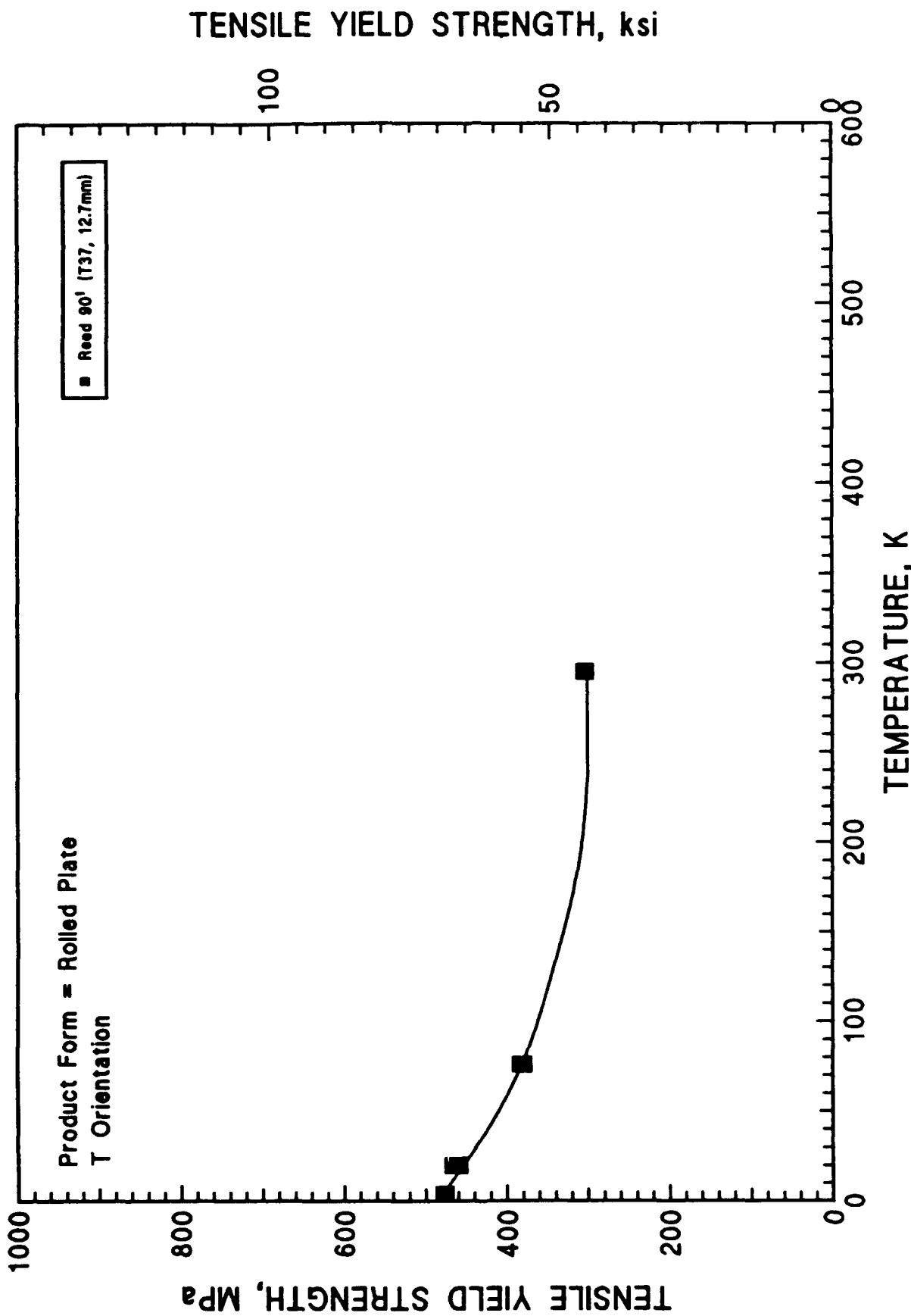


2219-T3

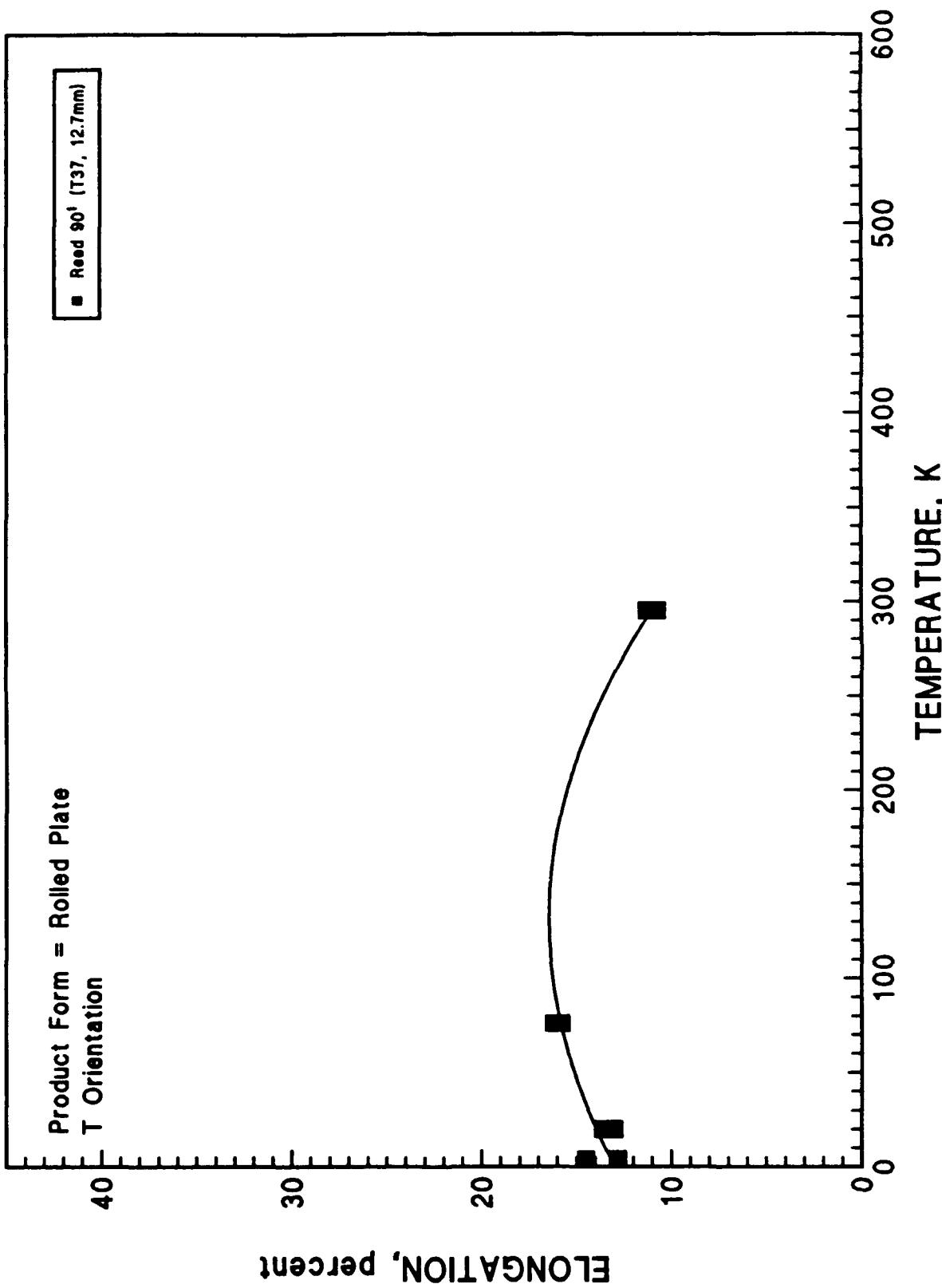
ULTIMATE TENSILE STRENGTH, ksi



2219-T3

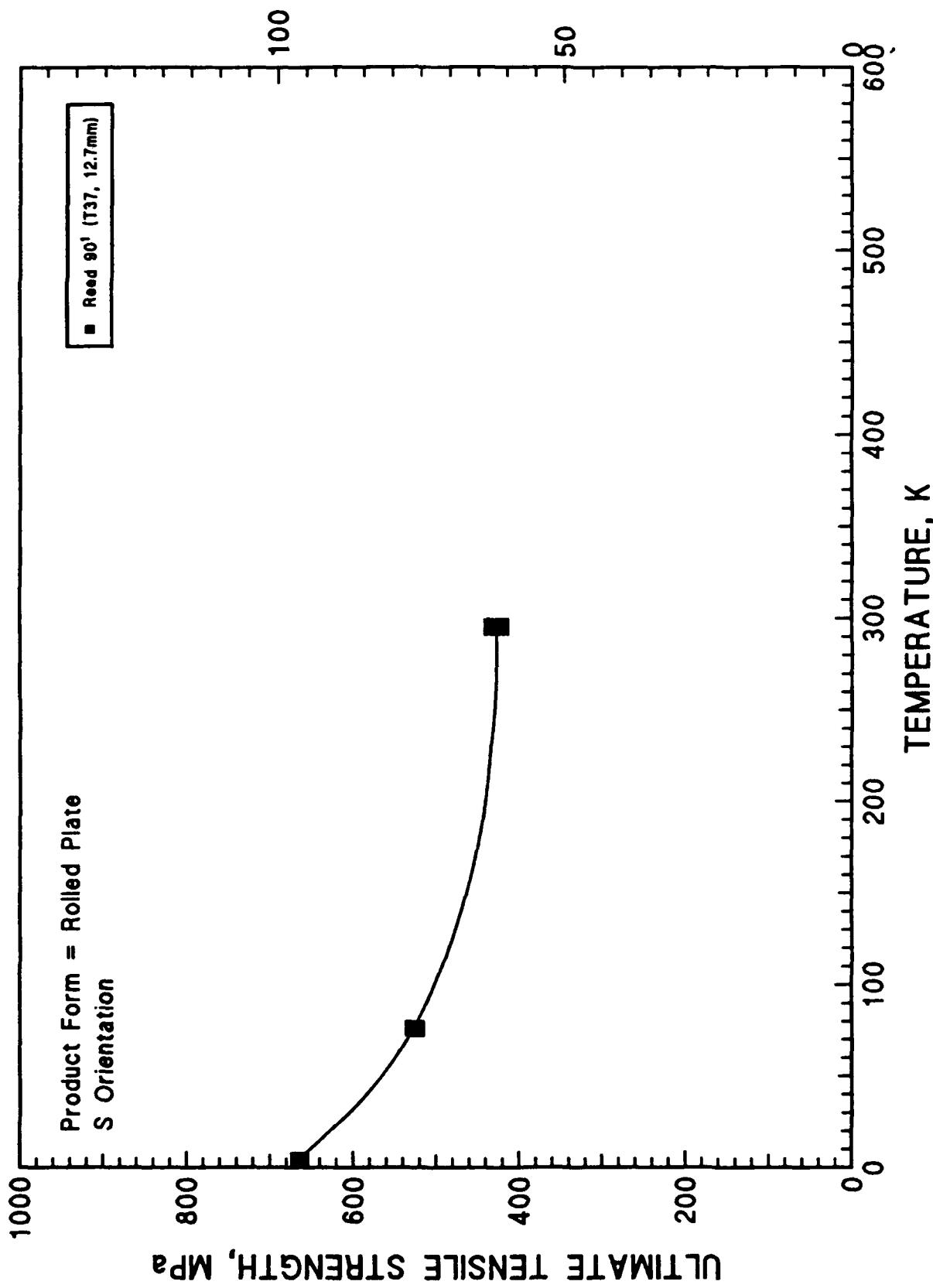


2219-T3



2219-T3

### ULTIMATE TENSILE STRENGTH, ksi



## Al-Li ALLOY 2219

Ref. & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Temper Form	Product Thickness mm	Aging Temp. °C	Time h	Stretch Z	Quench Temp. °C	Time h	Soln. Treat. Cond.	Grain Size μm	Hardness	Tests/ Data Pt	
1Q	295	472.	385.	13.	33.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
1Q	295	472.	387.	13.	31.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	582.	461.	14.	31.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	583.	464.	14.	31.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	707.	504.	15.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	701.	506.	14.	29.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
21A	298	465.	383.	11.8	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
21A	193	498.	413.	12.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
21A	77	578.	462.	14.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
21A	20	680.	499.	15.2	21.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
21A	4	676.	518.	15.5	24.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
21A	4	672.	505.	15.	22.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	300	463.	376.	17.3	30.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	300	483.	395.	16.4	29.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
22A	300	456.	374.	14.7	26.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	194	509.	410.	14.7	28.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
22A	194	487.	400.	14.7	26.5	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Temper Form	Product Thickness mm	Aging Temp. °C	Time h	Stretch X	Quench Temp. °C	Time h	Cond.	Grain Size μm	Hardness	Tests/ Data Pt
22A	194	463.	393.	14.2	27.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	194	507.	416.	15.6	27.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	77	565.	462.	18.2	30.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	77	578.	465.	15.6	28.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	77	578.	457.	16.4	28.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	77	563.	452.	16.4	28.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	20	655.	491.	22.2	28.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	20	663.	502.	17.3	27.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	20	639.	487.	0.	27.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	20	703.	534.	20.4	25.5	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
23A	300	469.	385.	10.8	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23A	300	458.	376.	10.7	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23A	77	576.	454.	12.8	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23A	77	581.	461.	12.2	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23A	20	676.	465.	16.	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23A	20	665.	489.	12.5	0.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
23B	300	469.	386.	9.6	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23B	77	592.	470.	11.2	0.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
23B	20	687.	476.	10.	0.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. z	Product Form	Thickness mm	Temp. °C	Time h	Agings z	Agings h	Soln. Treat. Cond.	Quench Time	Grain Size μm	Hardness	No. of Tests/ Data Pt.
23C	300	479.	382.	10.	0.	L	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	1
23C	300	473.	393.	9.7	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
23C	77	601.	479.	12.5	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
23C	77	616.	489.	10.5	0.	L	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	1
23C	20	673.	532.	12.	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
23C	20	700.	521.	7.5	0.	L	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	1
23D	300	468.	388.	10.3	0.	L	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	1
23D	77	594.	472.	12.3	0.	L	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	1
23D	20	601.	514.	11.7	0.	L	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	1
23E	300	455.	379.	6.3	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	300	456.	379.	6.6	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	300	482.	398.	6.7	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	300	487.	403.	6.7	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	300	457.	383.	6.6	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	77	592.	471.	7.3	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	77	591.	463.	7.3	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	77	576.	466.	5.6	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	77	619.	492.	10.2	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	77	616.	490.	8.5	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper T87	Product Form			Aging Time h	Stretch X °C	Quench h	Solv. Treat. Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
								Thickness mm	Temp. °C	Time h							
23E	20	632.	507.	6.7	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	703.	527.	6.52	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	696.	510.	6.7	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	725.	538.	9.5	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
24A	300	465.	388.	11.8	26.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
24A	194	496.	413.	12.	26.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
24A	78	576.	462.	14.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
26A	287	476.	378.	12.	18.4	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	297	487.	368.	11.5	15.1	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	297	473.	372.	11.5	19.3	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	287	482.	362.	11.	15.1	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	78	560.	430.	15.	29.4	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	78	563.	432.	16.	26.6	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	78	587.	444.	14.	19.1	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	20	659.	568.	12.6	16.0	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	20	647.	490.	15.5	13.4	L	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
27A	295	477.	387.	14.	29.	L	T87	Rolled Plate	15.0	NA	NA	NA	NA	NA	NA	NA	1
27A	295	479.	386.	14.	31.	L	T87	Rolled Plate	15.0	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper T87	Product Form	Thickness mm	Temp. °C	Time h	Stretch Z	Stretch Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	Soln. Treat.	No. of Tests/ Data Pt.
27A	77	592.	462.	15.	29.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	77	587.	463.	15.	29.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	20	635.	485.	0.	21.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	20	647.	501.	0.	22.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
30A	295	476.	393.	12.	0.	L	T87	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
30A	77	600.	483.	12.	0.	L	T87	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
30A	20	724.	510.	11.	0.	L	T87	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	300	471.	382.	13.	27.8	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	300	470.	381.	12.5	24.8	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	78	574.	439.	14.	25.3	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	78	583.	452.	15.	25.4	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	20	682.	470.	16.5	20.	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	20	683.	478.	16.5	18.5	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
32A	295	469.	379.	10.	26.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
32A	78	572.	448.	13.	22.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
32A	20	669.	462.	15.	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
33A	295	479.	403.	12.	20.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
33A	295	477.	397.	12.	30.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
33A	20	683.	497.	17.	22.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. L	Temper Form	Product Thickness mm	Temp. °C	Time h	Stretch Z	Temp. °C	Quench h	Soln. Treat. Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt.
33A	20	690.	492.	17.	24.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
35A	295	432.	350.	16.	37.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	295	432.	357.	16.	34.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	295	435.	354.	14.	31.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	295	435.	352.	13.	31.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	295	301.	243.	12.	26.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	665.	463.	18.	27.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	685.	472.	16.	31.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	681.	466.	16.	23.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	657.	469.	15.	26.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	656.	461.	15.	27.	L	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	128 RB	1
1R	297	447.	340.	8.9	17.5	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.6	1
1R	297	447.	343.	7.6	20.2	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.6	1
1R	76	557.	407.	9.5	23.6	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.6	1
1R	20	639.	427.	11.	19.5	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.6	1
1R	20	647.	432.	10.6	14.9	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.6	1
1R	4	659.	438.	9.	17.	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.6	1
1R	4	664.	441.	9.3	13.6	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.6	1

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. X	Temper T37	Product Form Rolled Plate	Thickness mm	Temp. °C	Time h	Stretch X	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	Testa/ Data Pt.
1T	295	390.	333.	11.9	30.7	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	295	392.	333.	12.3	26.5	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	76	511.	420.	20.1	29.4	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	76	509.	421.	14.7	25.7	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	20	670.	497.	17.7	16.2	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	20	661.	502.	17.4	22.9	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	4	672.	524.	17.3	20.6	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	4	671.	508.	16.6	24.3	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1Q	295	471.	380.	13.	27.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	295	472.	382.	13.	29.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	584.	457.	13.	23.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	580.	454.	13.	24.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	20	717.	526.	15.	13.4	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	702.	498.	14.	22.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	699.	500.	14.	23.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	300	465.	375.	13.9	20.1	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	300	460.	380.	12.9	23.5	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	300	465.	371.	12.7	0.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Product Form	Thickness mm	Product Temp. °C	Time h	Stretch %	Quench Cond.	Grain Size μm	Hardness	Tests/ Date Pt	
22A	194	491.	376.	11.1	19.1	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	194	491.	391.	11.1	16.7	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	194	497.	403.	13.6	19.1	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	194	499.	400.	12.9	24.5	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	77	579.	456.	12.9	21.1	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	77	565.	445.	14.7	22.5	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	77	573.	455.	12.9	24.5	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	20	663.	525.	16.9	24.5	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	20	662.	469.	16.4	19.1	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	1
22A	20	638.	459.	15.6	26.5	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
22A	20	663.	462.	17.3	23.5	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
23A	300	471.	381.	9.6	NA	T	T67	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23A	300	464.	374.	11.3	NA	T	T67	Rolled Plate	9.525	NA	NA	NA	NA	NA	NA	1
23A	77	594.	460.	9.6	NA	T	T67	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23A	77	585.	449.	11.2	NA	T	T67	Rolled Plate	9.525	NA	NA	NA	NA	NA	NA	1
23A	20	690.	485.	14.3	NA	T	T67	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	1
23B	300	460.	377.	8.5	NA	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1
23B	77	585.	466.	10.3	NA	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. T	Temper T	Product Form	Thickness mm	Aging Temp. °C	Time h	Stretch T	Temp. °C	Quench h	Treat. Cond.	Soln. NA	Grain Size μm	Hardness NA	No. of Tests/ Date Pt
23B	20	690.	496.	9.8	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	300	469.	365.	9.5	NA	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	300	472.	365.	8.	NA	T	T87	Rolled Plate	50.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	77	619.	495.	7.	NA	T	T87	Rolled Plate	50.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	77	597.	465.	9.3	NA	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	20	696.	496.	14.3	NA	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	20	692.	503.	6.3	NA	T	T87	Rolled Plate	50.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23D	300	464.	380.	7.5	NA	T	T87	Rolled Plate	30.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23D	77	592.	451.	7.	NA	T	T87	Rolled Plate	30.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23D	20	670.	481.	8.8	NA	T	T87	Rolled Plate	30.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	460.	381.	5.7	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	443.	370.	5.	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	464.	386.	6.3	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	473.	393.	6.5	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	580.	500.	6.2	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	581.	500.	6.	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	603.	476.	7.8	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	554.	427.	4.7	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. T	Temper T67	Product Form	Thickness mm	Aging Temp. °C	Time h	Stretch X	Quench Cond.	Soln. Treat. Time °C	Grain Size μm	Hardness	No. of Tests/ Data Pt
23E	77	394.	461.	6.3	NA	T	T67	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	650.	482.	5.5	NA	T	T67	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	616.	474.	4.6	NA	T	T67	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	651.	497.	5.5	NA	T	T67	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	692.	502.	0.2	NA	T	T67	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	684.	500.	8.	NA	T	T67	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
24A	300	470.	388.	10.	19.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
24A	184	301.	410.	9.6	16.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
24A	78	385.	465.	11.6	20.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
25A	295	473.	383.	10.	18.	T	T67	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	295	474.	383.	10.	13.	T	T67	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	78	383.	454.	9.	14.	T	T67	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	78	380.	452.	12.	15.	T	T67	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	20	696.	488.	13.	14.	T	T67	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	20	694.	494.	11.	12.	T	T67	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
26A	297	478.	377.	11.5	9.6	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	1
26A	297	481.	378.	11.	6.7	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	1
26A	78	363.	434.	14.5	25.1	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper T	Product Form	Thickness mm	Temp. °C	Time h	Stretch Z	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
26A	78	592.	439.	11.	12.9	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	NA	1
26A	78	581.	453.	12.5	15.1	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	NA	1
26A	78	592.	439.	10.	16.5	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	NA	1
26A	20	595.	465.	11.	11.1	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	NA	1
26A	20	633.	461.	6.7	13.	T	T67	Rolled Plate	62.6	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	285	478.	366.	14.	31.	T	T67	Rolled Plate	15.0	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	77	598.	450.	12.	16.	T	T67	Rolled Plate	15.0	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	77	599.	456.	12.	19.	T	T67	Rolled Plate	15.0	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	20	634.	0.	0.	16.	T	T67	Rolled Plate	15.0	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	20	0.	492.	0.	16.	T	T67	Rolled Plate	15.0	NA	NA	NA	NA	NA	NA	NA	NA	1
28A	300	483.	300.	10.5	16.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1
28A	77	547.	456.	9.5	18.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1
28A	20	697.	494.	7.	19.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1
28A	20	716.	521.	9.5	25.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1
29A	300	479.	366.	10.5	0.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1
29A	77	591.	468.	10.	0.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1
29A	77	592.	467.	10.5	0.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1

\*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. I	Temper T	Product Form	Thickness mm	Product Temp. °C	Time h	Stretch I	Soln. Treat. Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	Tests/ Date Pt	No. of Tests
29A	20	683.	470.	13.	0.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1	
29A	20	711.	530.	12.	0.	T	T67	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1	
30A	295	476.	375.	10.	0.	T	T67	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1	
30A	295	476.	386.	8.	0.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1	
30A	77	593.	455.	12.	0.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1	
30A	77	593.	462.	11.	NA	T	T67	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1	
30A	20	690.	478.	11.	0.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1	
30A	20	696.	503.	10.	NA	T	T67	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1	
31A	300	472.	374.	80.	10.4	T	T67	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1	
31A	300	474.	378.	7.5	11.9	T	T67	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1	
31A	78	594.	464.	10.5	12.0	T	T67	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1	
31A	78	585.	455.	11.	13.3	T	T67	Rolled Plate	19.5	NA	NA	NA	NA	NA	NA	NA	NA	1	
31A	20	700.	490.	12.	11.6	T	T67	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1	
31A	20	693.	496.	14.3	14.6	T	T67	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1	
32A	295	476.	386.	8.	15.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1	
32A	78	593.	455.	12.	14.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1	
32A	20	690.	476.	11.	13.	T	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1	
33A	295	485.	402.	9.	19.	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1	
33A	295	465.	399.	9.	17.	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1	

\*See Comments

Ref & No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper T	Product Form	Thickness mm	Temp. °C	Time h	Stretch Z	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	Testa/ Date Pt	No. of Testa
33A	20	700.	502.	15.	16.	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1	
33A	20	702.	502.	14.	17.	T	T67	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1	
34A	300	503.	412.	NA	NA	T	T67	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	NA	1	
34A	300	509.	411.	NA	NA	T	T67	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	NA	1	
34A	76	630.	490.	NA	NA	T	T67	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	NA	1	
34A	76	630.	496.	NA	NA	T	T67	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	NA	1	
34A	4	706.	514.	NA	NA	T	T67	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	NA	1	
34A	4	734.	547.	NA	NA	T	T67	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	NA	1	
1R	287	444.	332.	7.7	13.6	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1R	287	443.	330.	8.2	16.3	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1R	76	559.	403.	9.	14.6	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1R	76	557.	406.	8.9	17.2	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1R	20	658.	420.	10.5	15.8	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1R	20	641.	419.	11.2	18.	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1R	4	663.	435.	9.6	15.8	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1T	295	396.	303.	11.3	25.	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1T	285	400.	304.	10.7	24.3	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1T	76	518.	383.	16.2	20.	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	

\*See Comments

Ref & Note	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient.	Temper	Product Form	Thickness mm	Temp. °C	Time h	Stretch Z	Soiln. Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
1T	76	518.	379.	15.6	22.	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	20	671.	467.	13.6	19.8	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	20	662.	459.	13.	16.2	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	4	667.	476.	12.6	17.2	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	4	670.	478.	14.5	15.4	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1Q	295	469.	379.	13.	30.	45°	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	295	468.	378.	14.	33.	45°	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	378.	449.	14.	29.	45°	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	360.	450.	13.	26.	45°	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	704.	491.	15.	27.	45°	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	702.	491.	15.	28.	45°	T67	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
1S	295	478.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1S	295	462.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1U	295	432.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1U	295	422.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1U	76	524.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1U	76	527.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1U	4	663.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1
1U	4	665.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1

\*See Comments

**TEST PARAMETERS**  
Al-Li ALLOY 2219

Ref & No.	Strain Rate 10 <sup>-4</sup> /s	Type	Specimen Dim. mm	Thick. mm	G.I. mm	Specimen Location	Expo. Time min	Supplier Prod. No.	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements wt%				Minor Elements wt%			
												Li	Cu	Ag	Fe	Zr	Si		
1Q	2.2	Round	6.35	NA	25.4	Mid-plane	5.	NASA	1990	484881	0.307 X 0.307	NA	5.7	NA	0.01	0.07	0.02	NA	
1R	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Kaiser	1989	428881	1.02 X 1.02	NA	5.7	0.	0.15	0.07	0.02	NA	
1S	2.2	Round	2.5	NA	25.4	Random	5.	Kaiser	1989	429881	1.02 X 1.02	NA	5.7	NA	0.07	0.02	NA	NA	
1T	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Kaiser	1989	486341	1.02 X 1.02	NA	5.7	0.	0.15	0.07	0.02	NA	
1U	2.2	Round	2.5	NA	25.4	Random	5.	Kaiser	1989	486341	1.02 X 1.02	NA	5.7	NA	0.15	0.07	0.02	NA	
21A	7.4	NA	12.7	NA	57.	NA	15.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
22A	NA	Round	4.06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.16	0.2	0.3
23A	NA	NA	NA	NA	NA	50.0	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3
23B	NA	Flat	12.7	3.175	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3
23C	NA	Flat	25.4	3.175	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3
23D	NA	Flat	19.	3.175	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3
23E	NA	Flat	25.4	NA	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3
24A	NA	Flat	12.7	NA	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
25A	NA	Flat	13.	0.52	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
27A	.003	Flat	15.9	12.7	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3
28A	.003	Plate	12.7	NA	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3
29A	.003	Plate	12.7	NA	50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3

Ref & Note No.	Strain Rate 10 <sup>-4</sup> /s	Type	Specimen			Specimen Location	Expo Time min	Supplier	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements					Minor Elements wt%		
			Dia mm	Thick mm	G.L. mm							Li	Cu	Mg	Zr	Si	Fe	As	
30A	.003	Flat	12.7	MA	50.6	MA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
30B	.003	Flat	12.7	12.7	50.6	MA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
31A	.003	Flat	19.1	12.7	50.6	MA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
32A	.003	MA	MA	MA	50.6	MA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
33A	.002	Flat	12.7	7.62	50.6	MA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
34A	NA	MA	MA	MA	MA	MA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
35A	NA	MA	3.17	MA	12.7	MA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

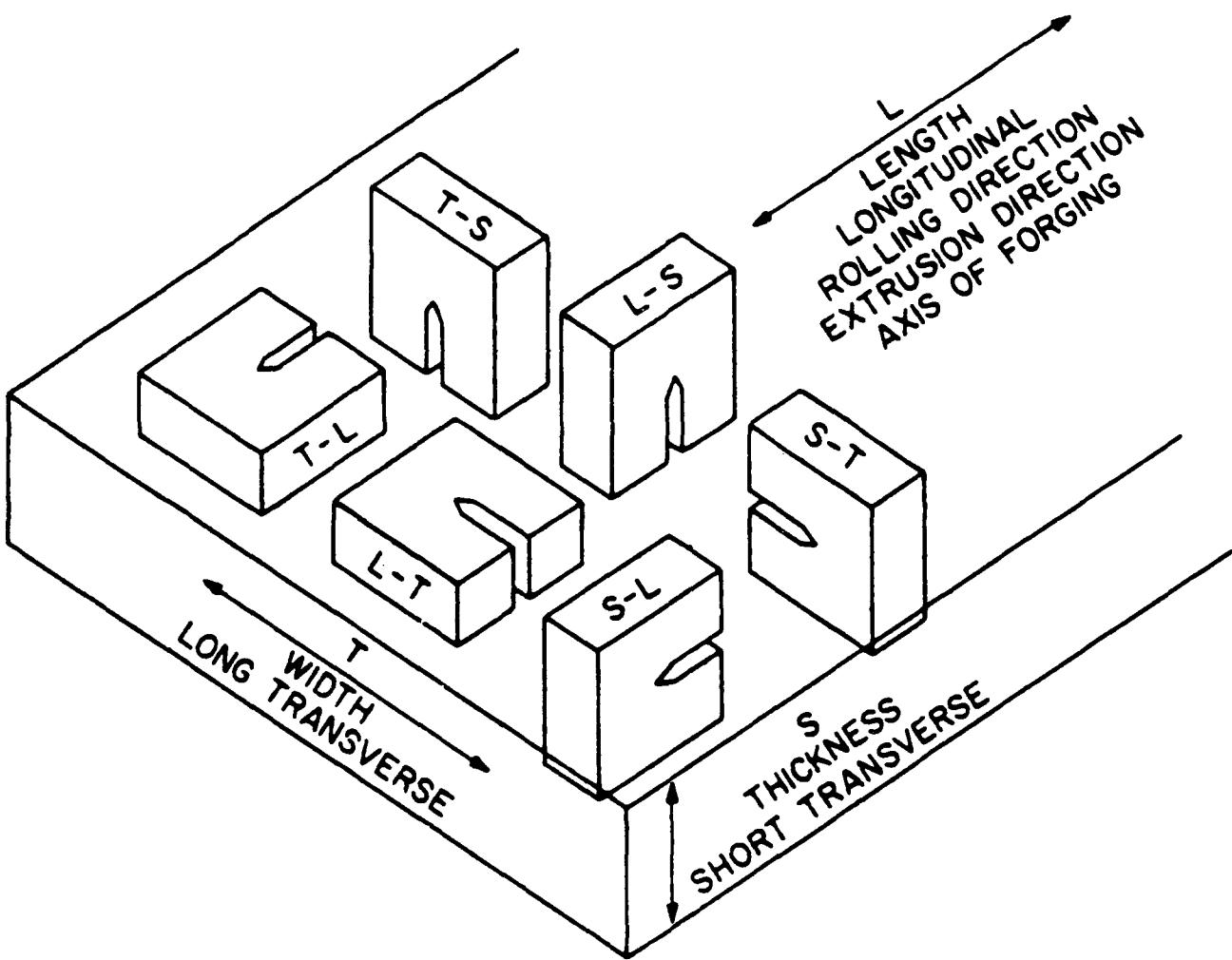
## 2. FRACTURE TOUGHNESS

### 2.1. Introduction to Graphs

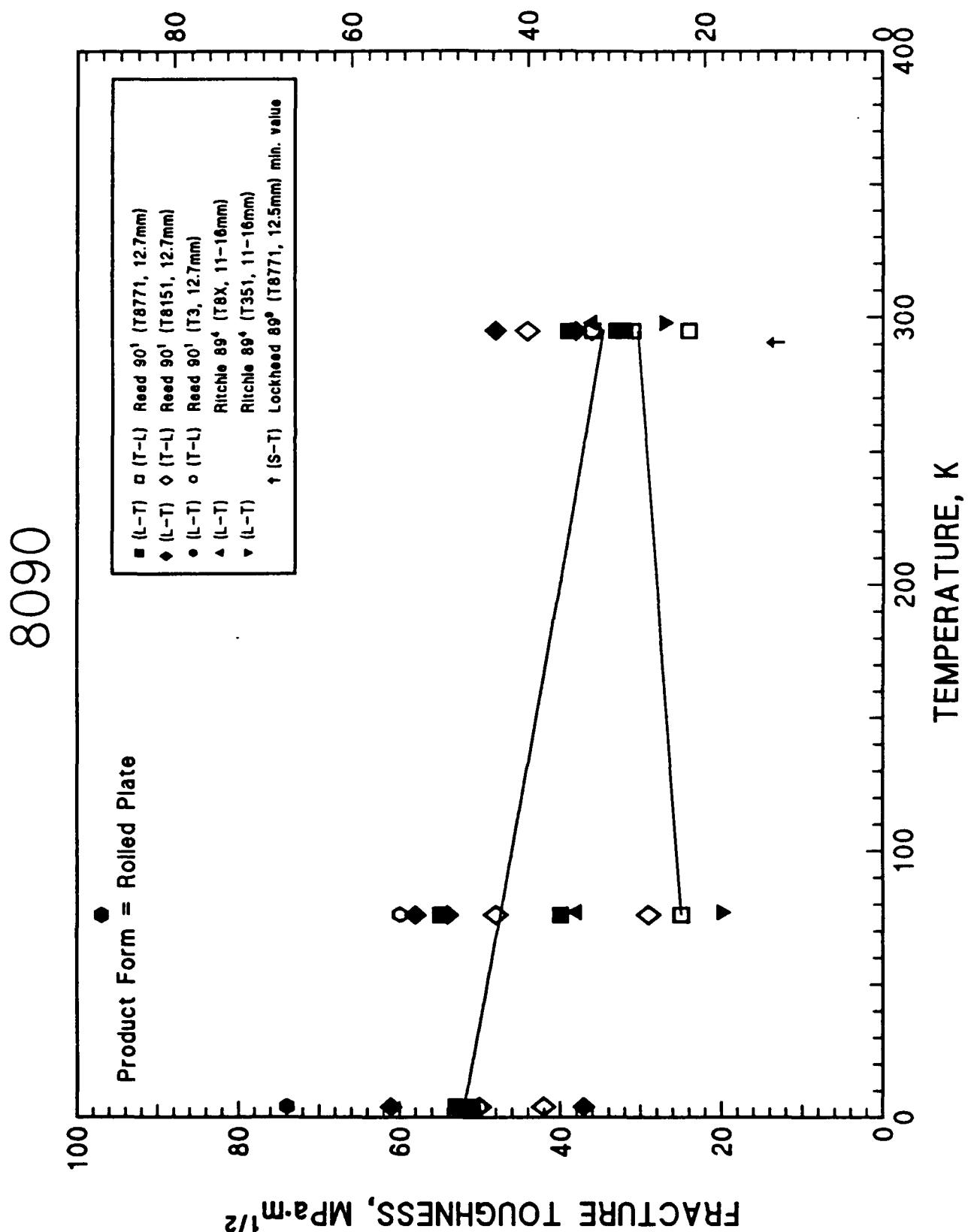
Fracture toughness data at room temperature are presented (with few exceptions) only when measurements at cryogenic temperatures are part of the data set. Thus, only  $K_{Ic}$  data on CT (compact tension) specimens are presented in this review. These data are currently available because measurements are relatively easy to carry out in conventional cryostats compared with wide-panel center-crack or part-through crack tests. Most of the measurements on current production vintages and tempers were carried out during the last year at NIST. These measurements are discussed more fully, including fracture mode and microstructural considerations, in another NIST report<sup>1</sup> on comparative cryogenic mechanical properties. A figure showing the possible specimen orientations with respect to the rolling direction precedes the graphs of fracture toughness data. The fracture toughness is presented graphically both as a function of temperature and as a function of yield strength.

All graphical data are presented and referenced in tables following the graphs. The properties presented in the data tables are the fracture toughness and yield strength, along with temper, product information, thermomechanical processing, grain size, hardness, number of tests per data point, and the reference and note number. The reference and note number is a guide to the accompanying test conditions table, which gives information on the specimen type and dimensions, precrack conditions, existance of side grooves or multiple specimens, invalidating criterion, chemistry, and procedures, including the test standard used. A list of comments follows the fracture toughness data table and the fracture toughness test conditions table for each alloy where necessary.

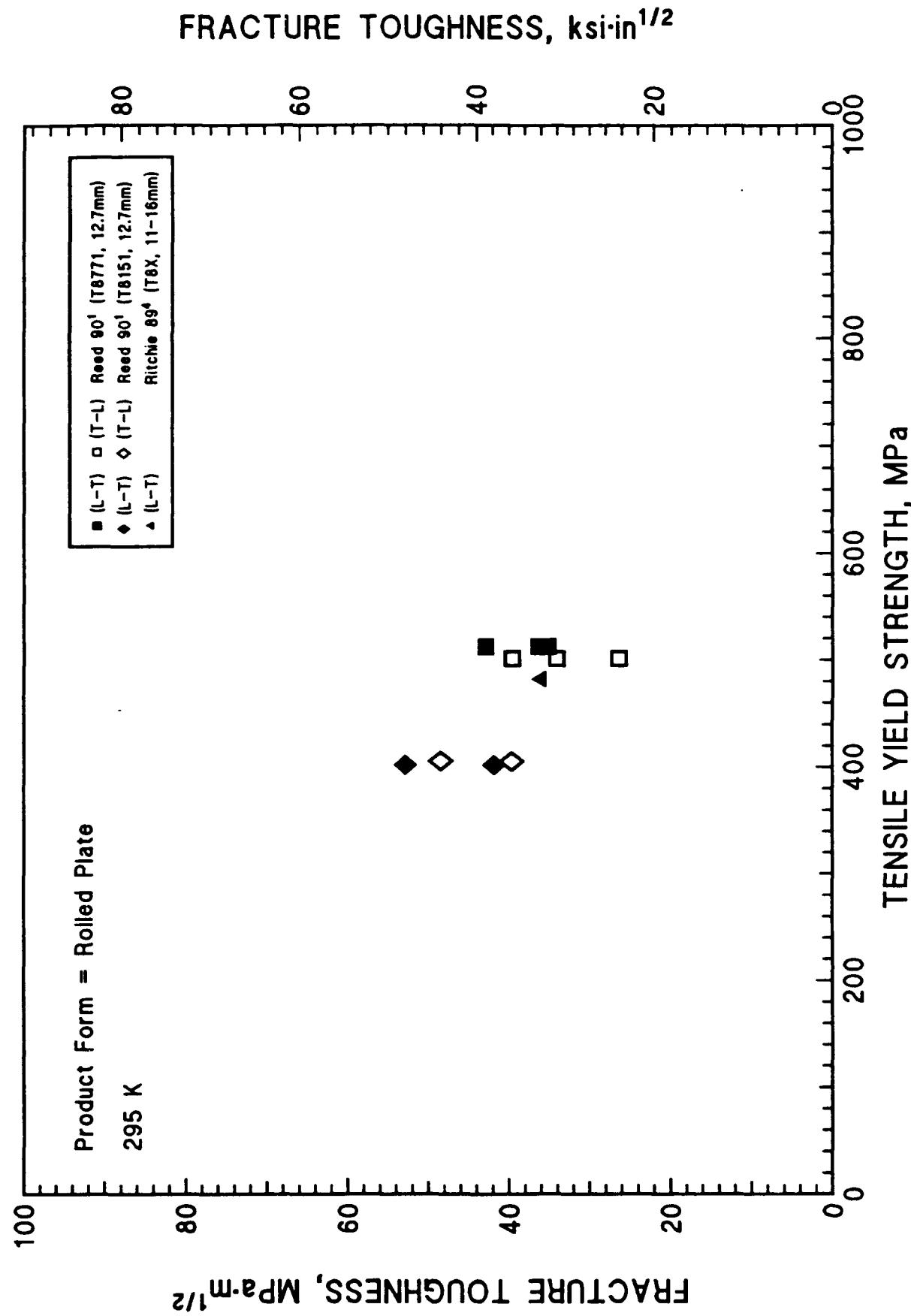
NIST is currently engaged in a program to expand the cryogenic fracture toughness database by testing 102-mm (4.0-in) panels with part-through cracks. The type of fracture toughness data presented in this new program is determined by design needs of the ALS program, where these alloys are under consideration for use in cryogenic tankage. Generally, a leak is equivalent to failure, so part-through cracks in wide panel testing are more relevant than center-crack tests. Wide panel testing at temperatures of 20 and 4 K is quite limited, and there are no data to report at present.



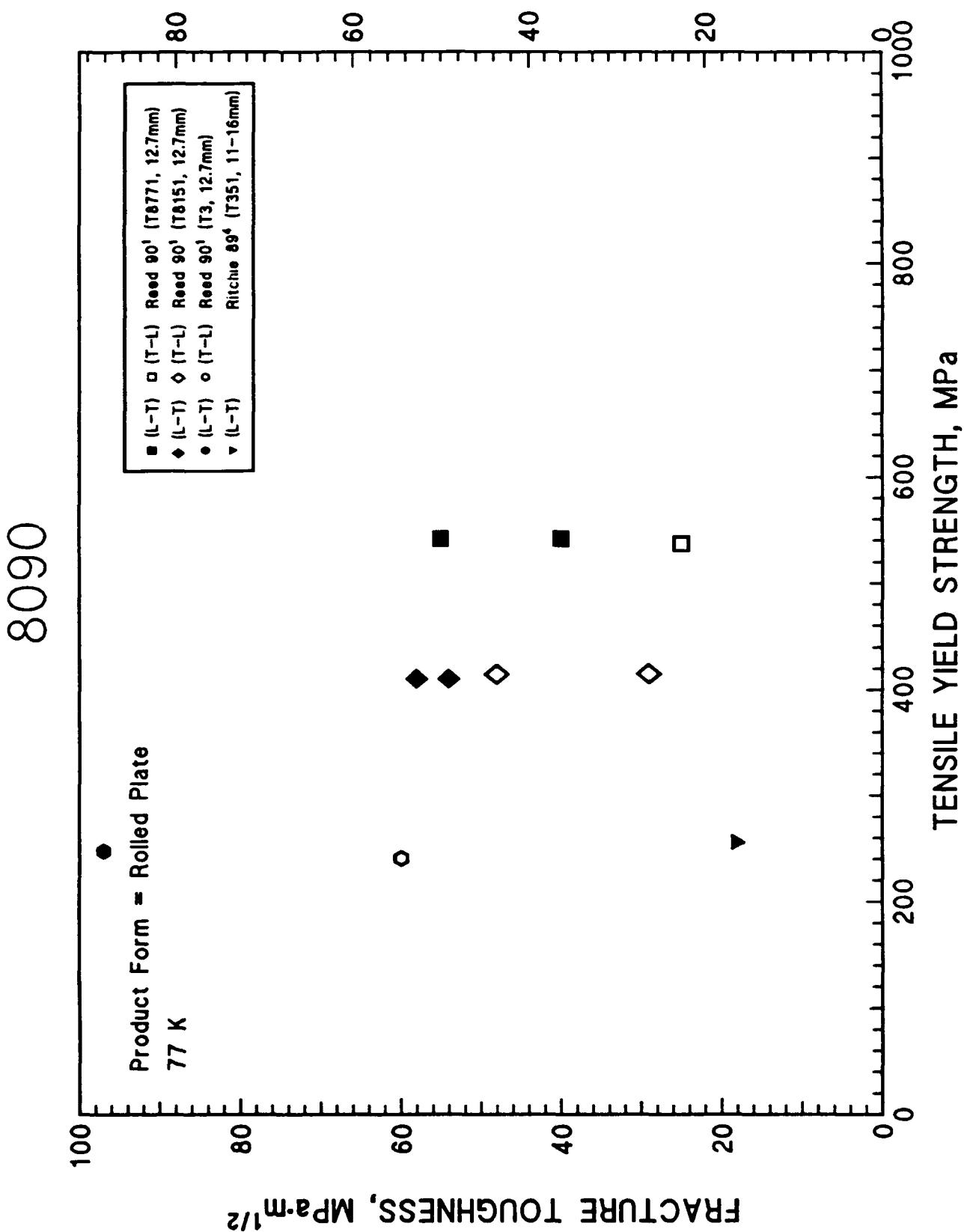
# FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>

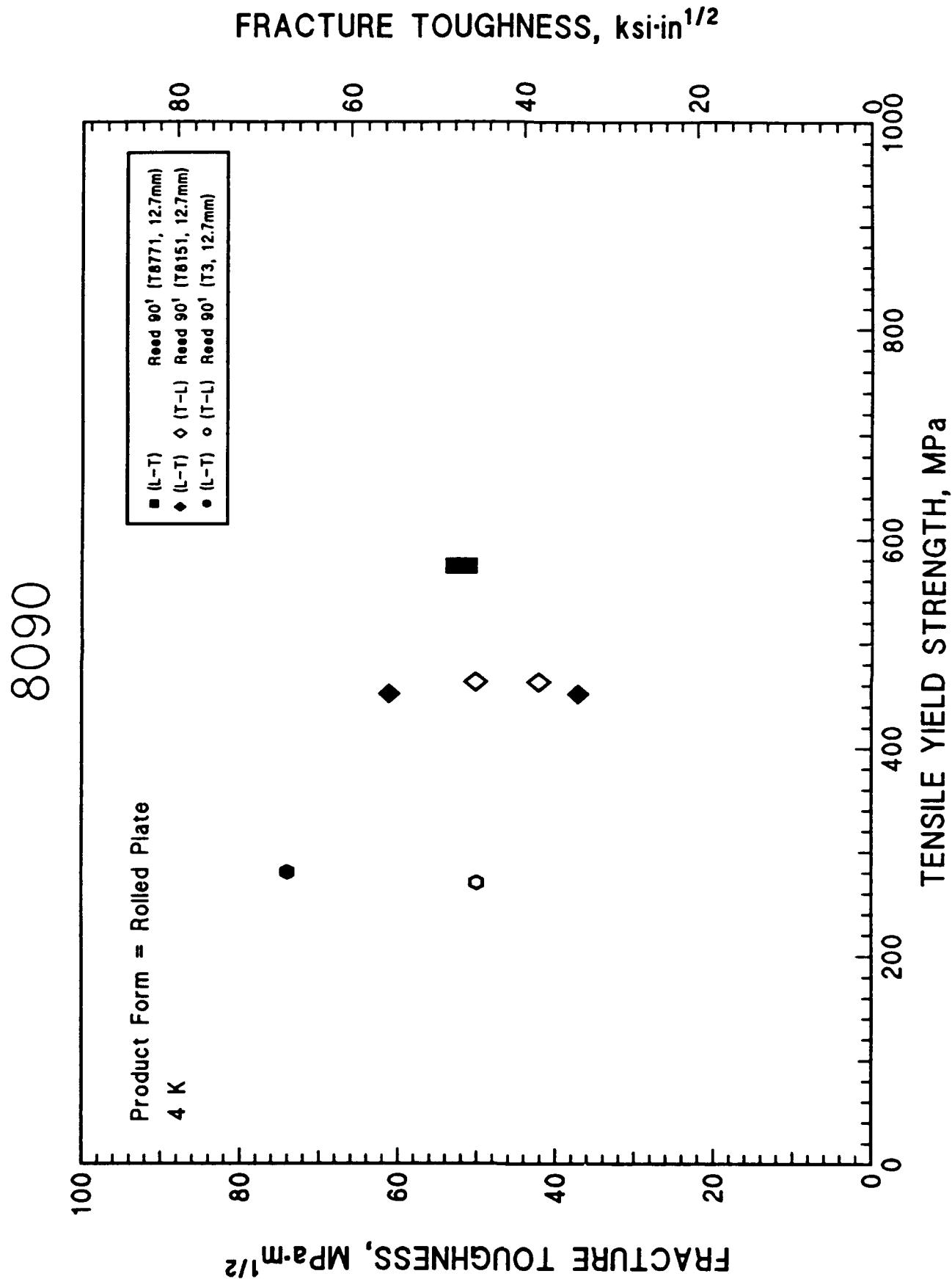


8090



# FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>





Fracture Toughness  
Alloy 8080

Ref & Note No.	Temp. K	Y.S. MPa/m MPa	Orient.	Temper	Product Form	Thickness mm	Supplier: Lot Number	Aging Temp. °C	Cold Work %	Soil Treat. Time h	Quench Temp. °C	Cond. μm	Grain Size			Hardness L X T X ST	No. of Tests/ Date Pt
													L	X	T		
1A	295	39.	512.	L-T	T6771	Rolled Plate	12.7	ALCAN; '88	:3503302B	NA	NA	6	NA	NA	NA	NA	1
1A	295	32.	512.	L-T	T6771	Rolled Plate	12.7	ALCAN; '88	:3503302B	NA	NA	6	NA	NA	NA	NA	1
1A	295	33.	512.	L-T	T6771	Rolled Plate	12.7	ALCAN; '88	:3503302B	NA	NA	6	NA	NA	NA	NA	1
1B	76	40.	542.	L-T	T6771	Rolled Plate	12.7	ALCAN; '88	:3503302B	NA	NA	6	NA	NA	NA	NA	1
1B	76	55.	542.	L-T	T6771	Rolled Plate	12.7	ALCAN; '88	:3503302B	NA	NA	6	NA	NA	NA	NA	1
1B	4	53.	574.	L-T	T6771	Rolled Plate	12.7	ALCAN; '88	:3503302B	NA	NA	6	NA	NA	NA	NA	1
1B	4	51.	574.	L-T	T6771	Rolled Plate	12.7	ALCAN; '88	:3503302B	NA	NA	6	NA	NA	NA	NA	1
1C	295	38.	402.	L-T	T6151	Rolled Plate	12.7	ALCAN; '88	:35712659	NA	NA	NA	NA	NA	NA	NA	1
1C	295	46.	402.	L-T	T6151	Rolled Plate	2.7	ALCAN; '88	:35712652	NA	NA	NA	NA	NA	NA	NA	1
1D	76	58.	411.	L-T	T6151	Rolled Plate	12.7	ALCAN; '88	:35712659	NA	NA	NA	NA	NA	NA	NA	1
1D	76	54.	411.	L-T	T6151	Rolled Plate	12.7	ALCAN; '88	:35712652	NA	NA	NA	NA	NA	NA	NA	1
1D	4	61.	452.	L-T	T6151	Rolled Plate	12.7	ALCAN; '88	:35712652	NA	NA	NA	NA	NA	NA	NA	1
1E	76	97.	248.	L-T	T3	Rolled Plate	12.7	ALCAN; '88	:3516302A	NA	NA	2	NA	NA	NA	600	118.5. V
1E	4	74.	280.	L-T	T3	Rolled Plate	12.7	ALCAN; '88	:3516302A	NA	NA	2	NA	NA	NA	20	118.5. V

Ref & Note No.	Temp. K	K MPa/in MPa	Y.S. MPa	Orient.	Temper	Product Form	Thickness mm	Supplier; Year; Lot Number	Aging Temp. °C	Cold Work h	Soln Treat. Time °C	Quench h	L X T X ST μm	Grain Size	Hardness Rocke/ Data Pt	
1A	295	31.	501.	T-L	T6771	Rolled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	6	NA	NA	NA	NA	1
1A	295	36.	501.	T-L	T6771	Rolled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	6	NA	NA	NA	NA	1
1A	295	24.	501.	T-L	T6771	Rolled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	6	NA	NA	NA	NA	1
1B	76	25.	537.	T-L	T6771	Rolled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	6	NA	NA	NA	NA	1
1C	295	36.	405.	T-L	T6151	Rolled Plate	12.7	ALCAN; '89 ;35712859	NA	NA	NA	NA	NA	NA	NA	1
1C	295	44.	405.	T-L	T6151	Rolled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	1
1D	76	29.	415.	T-L	T6151	Rolled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	1
1D	76	48.	415.	T-L	T6151	Rolled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	1
1D	4	42.	463.	T-L	T6151	Rolled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	1
1D	4	50.	463.	T-L	T6151	Rolled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	1
1E	76	60.	241.	T-L	T3	Rolled Plate	12.7	ALCAN; '89 ;3516302A	NA	NA	2	NA	NA	600	NA	118.5, V
1E	4	50.	270.	T-L	T3	Rolled Plate	12.7	ALCAN; '89 ;3516302A	NA	NA	2	NA	NA	600	NA	118.5, V
8A	295	13.2	MA	T-S	T6771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	*

Comments from the Al-Li Alloy 8090 Data Table

Reference and  
Note Number

9A--Values reported are "minimum" properties.

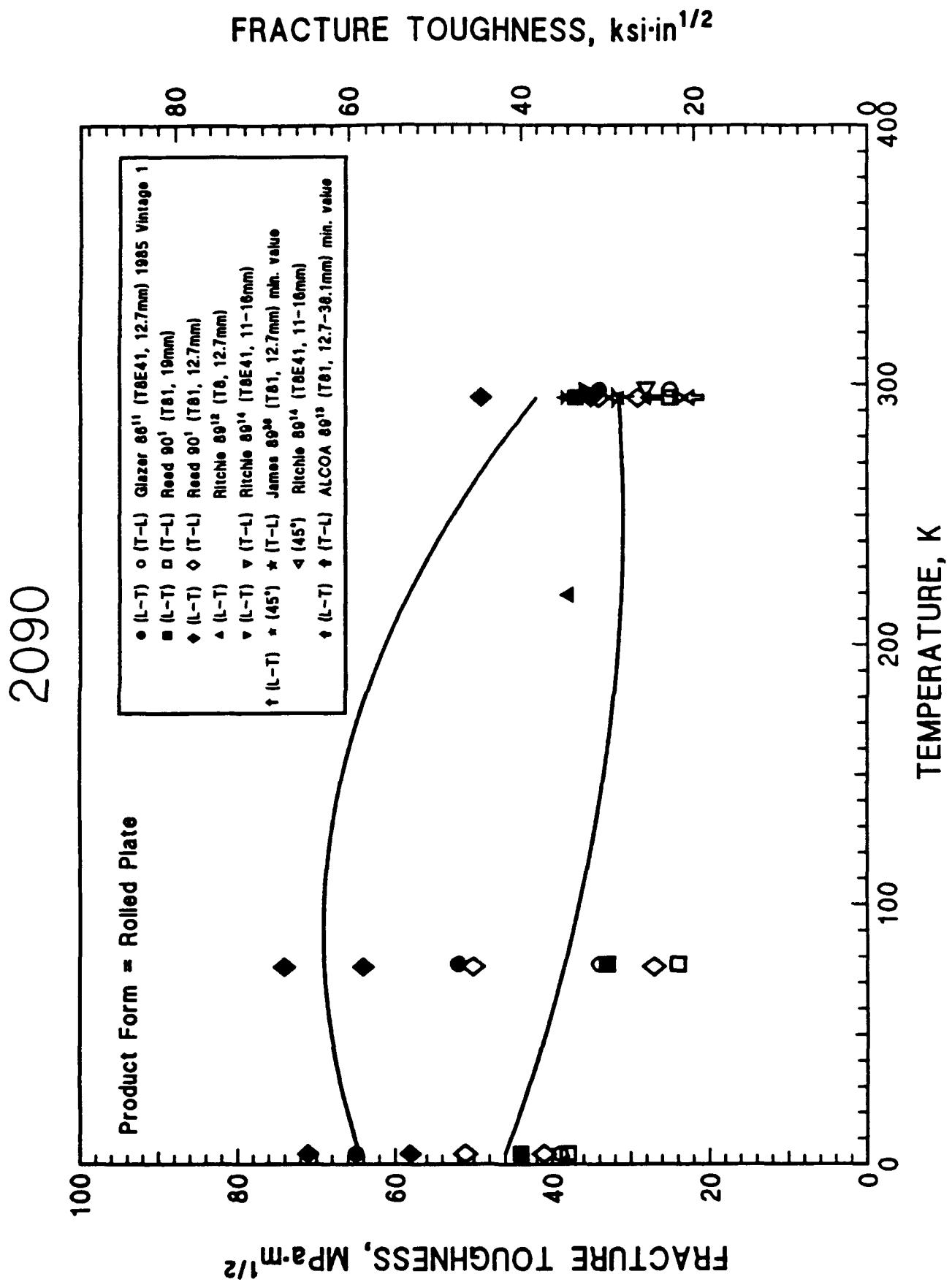
Fracture Toughness  
Test Conditions  
Alloy 6090

Ref No.	Specimen Type	Specimen Dimensions			Porecrack Temp K	Freq Hz	Side-Groove	Multi-Spec. no/#	Invalidating Criterion	Major Elements wt%				Procedures				
		B	W	e/H						Li	Cu	Hg	Zr	Si				
1A	CT	12.7	50.0	NA	NA	295	20.	no	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1B	CT	12.7	50.0	NA	NA	76	20.	no	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1C	CT	12.7	50.0	NA	NA	295	20.	no	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1D	CT	12.7	50.0	NA	NA	76	20.	no	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1E	CT	12.7	50.0	NA	NA	76	20.	no	no	NA	2.34	1.2	0.6	0.12	0.03	0.05	NA	ASTM E813
4A	CT	7.6	NA	0.5	NA	NA	NA	NA	NA	NA	2.50	1.3	0.7	0.12	0.1	0.2	NA	ASTM E399-63
4B	CT	7.6	NA	0.5	NA	NA	NA	NA	NA	NA	2.50	1.3	0.7	0.12	0.1	0.2	NA	ASTM E399-63
4C	CT	7.6	NA	0.5	NA	NA	NA	NA	NA	NA	2.5	1.3	0.7	0.12	0.1	0.2	NA	ASTM E399-63
9A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Comments from the Al-Li Alloy 8090 Test Conditions Table

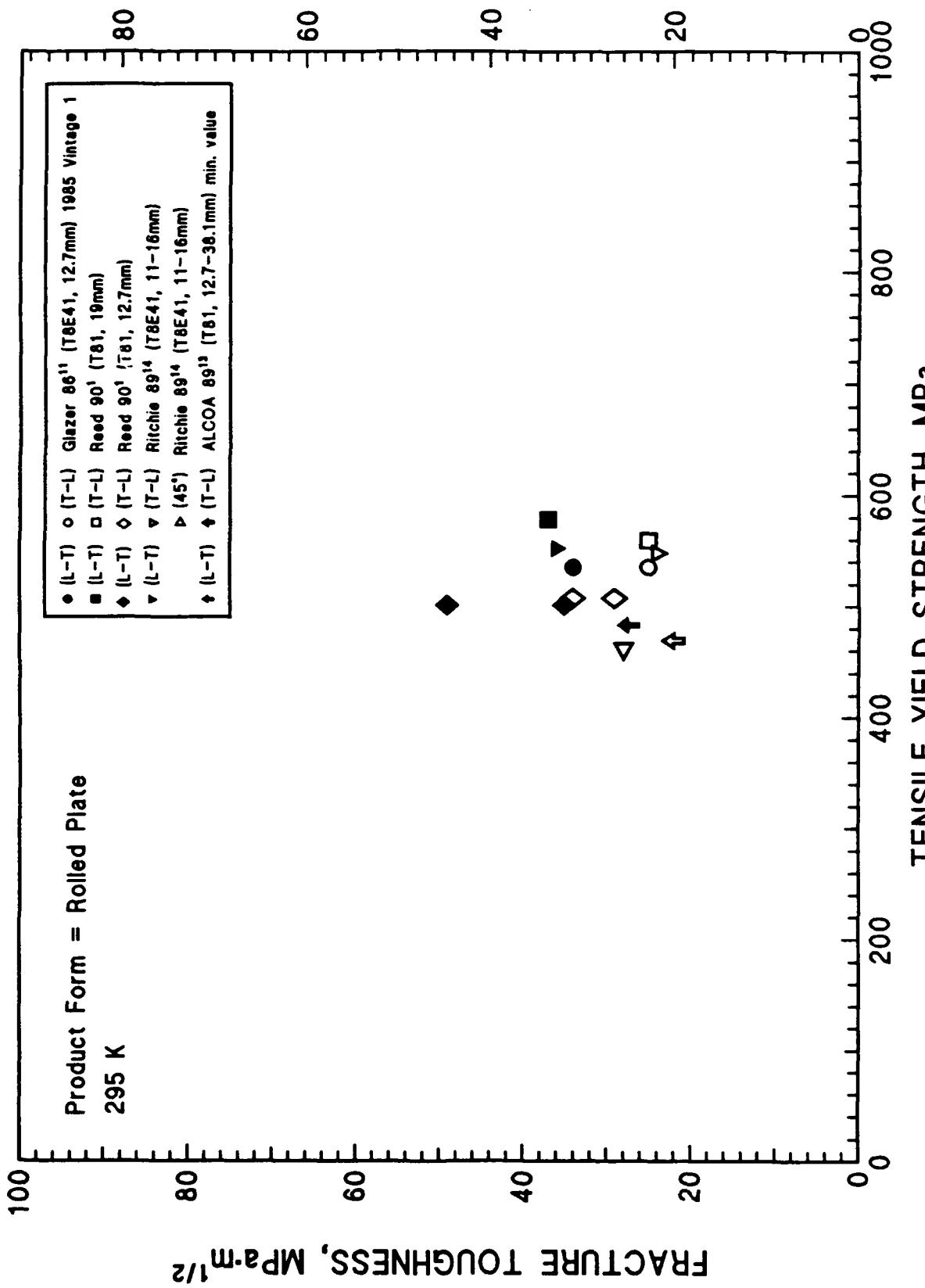
Reference and  
Note Number

9A--Reported composition is the average of the range provided for in the Lockheed requirements.



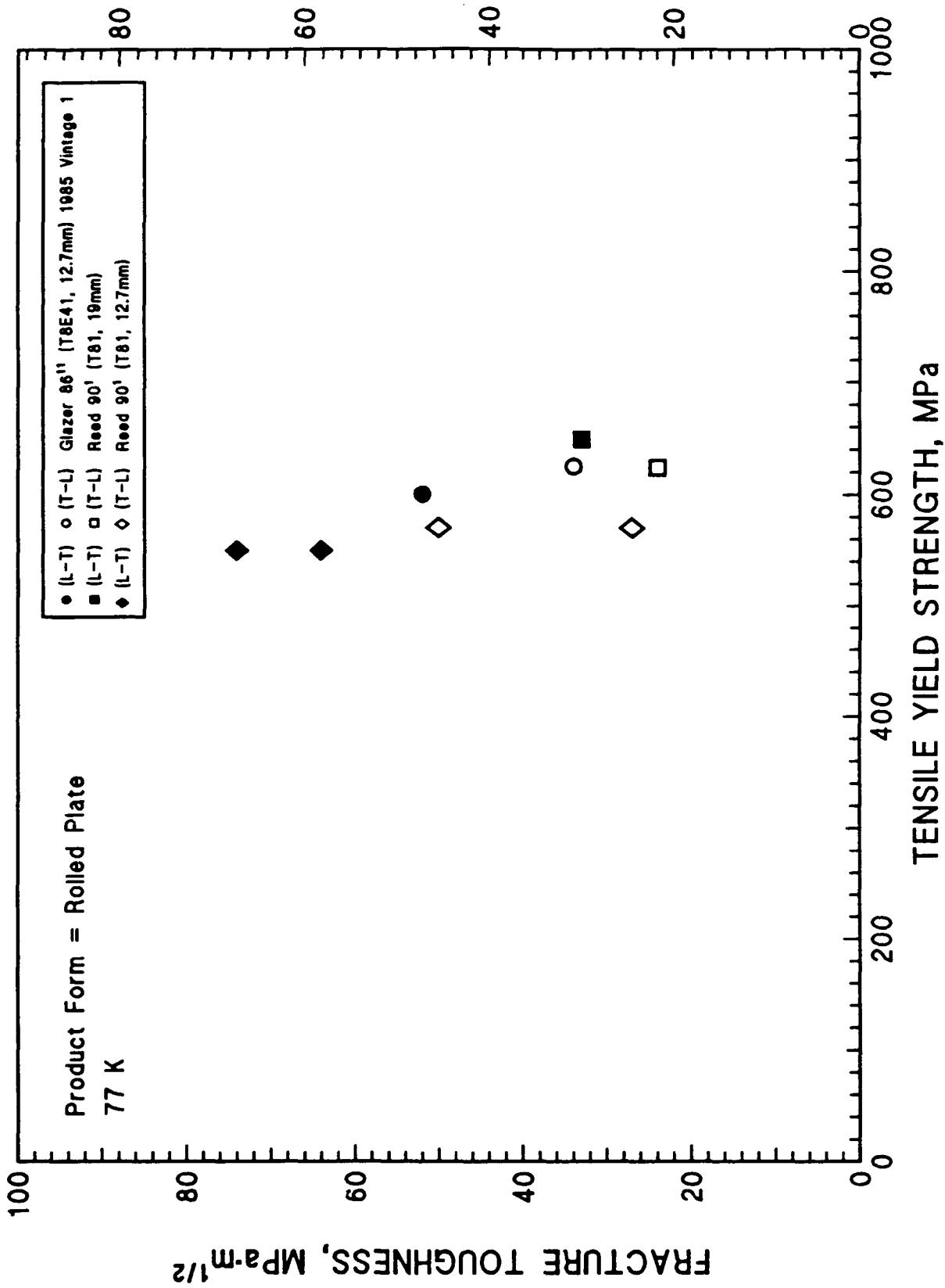
2090

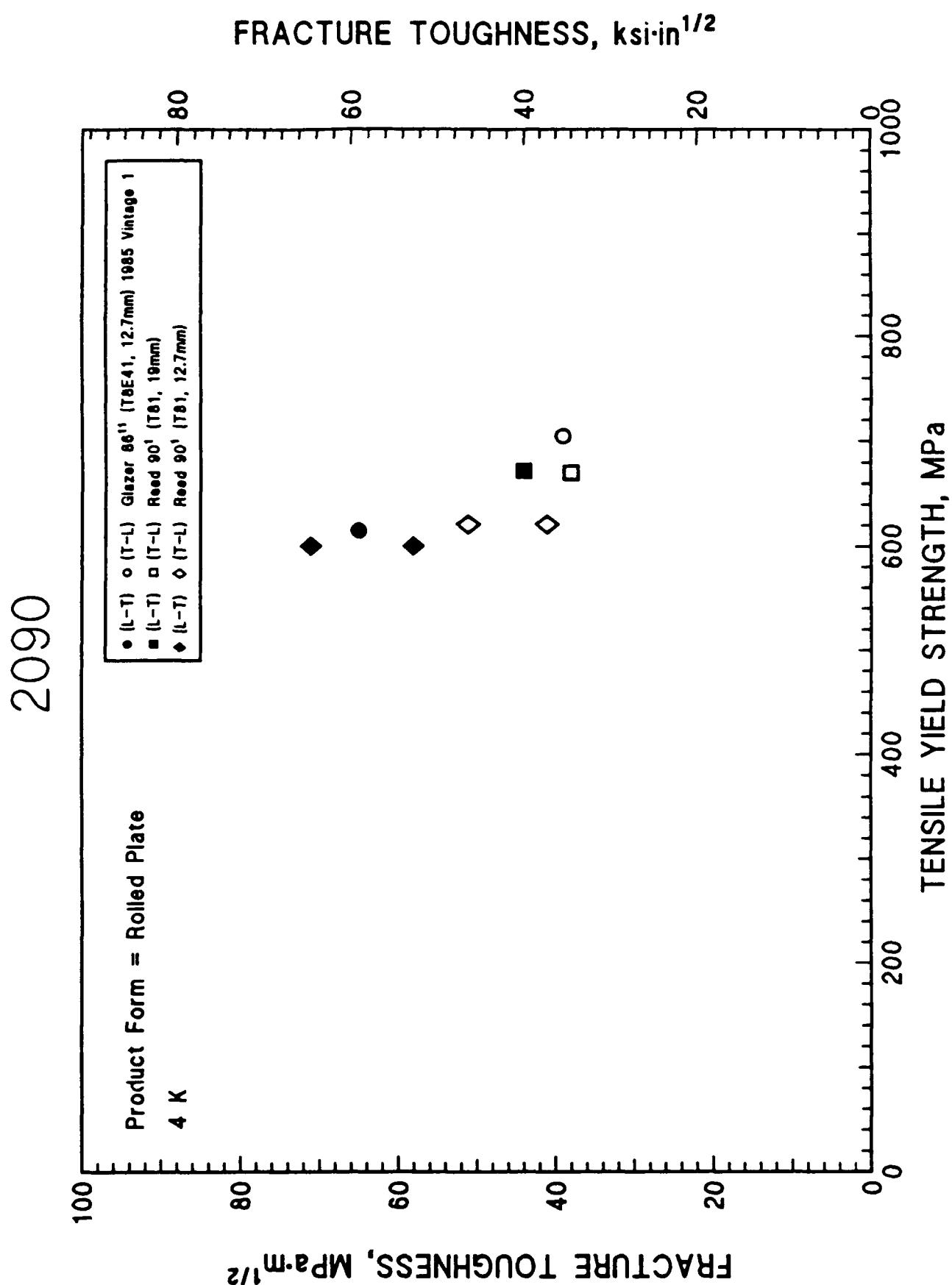
## FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>



2090

## FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>





Fracture Toughness  
Alloy 2090

Ref & Note No.	Temp. K	Y.S. MPa/m	Orient.	Temper	Product Form	Thickness, mm	Supplier: Lot Number	Year: 'xx	Aging Temp. °C	Cold Work h	Soil Treat. Time h	Quench Temp. °C	Time h	L X T X SI	Hardness μm	No. of Tests/ Data Pt.	
1F	295	49.	501.	L-T	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V
1F	295	35.	501.	L-T	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V
1G	77	64.	550.	L-T	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V
1G	77	74.	550.	L-T	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V
1G	4	71.	600.	L-T	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V
1G	4	38.	600.	L-T	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V
1H	295	37.	570.	L-T	T81	Rolled Plate	19.05	ALCOA; '89	:103299	NA	NA	NA	NA	2000	NA	100	198.3, V
1I	77	33.	649.	L-T	T81	Rolled Plate	19.05	ALCOA; '89	:103299	NA	NA	NA	NA	2000	NA	100	198.3, V
1I	4	44.	672.	L-T	T81	Rolled Plate	19.05	ALCOA; '89	:103299	NA	NA	NA	NA	2000	NA	100	198.3, V
12A	219	38.	565.	L-T	T81	Rolled Plate	12.7	ALCOA	;NA	NA	NA	NA	NA	NA	NA	NA	
13A	295	27.5	483.	L-T	T81	Rolled Plate	25.4	NA	;NA	NA	NA	NA	NA	NA	NA	*	
36B	295	27.5	NA	L-T	T81	Rolled Plate	12.7	NA	;NA	NA	NA	NA	NA	NA	NA	*	
11A	298	34.	535.	L-T	T8E41	Rolled Plate	12.7	ALCOA	;NA	NA	NA	NA	NA	NA	NA	1	
11A	77	52.	600.	L-T	T8E41	Rolled Plate	12.7	ALCOA	;NA	NA	NA	NA	NA	NA	NA	1	
11A	4	65.	615.	L-T	T8E41	Rolled Plate	12.7	ALCOA	;NA	NA	NA	NA	NA	NA	NA	1	
1F	295	34.	507.	T-L	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V
1F	295	28.	507.	T-L	T81	Rolled Plate	12.7	ALCOA; '89	:103301	NA	NA	NA	NA	2000	NA	200	198.3, V

Ref & Note No.	Temp. K	Y.S. MPa/m	Orient. K	Temper Form	Product Thickness mm	Supplier; Year; Lot Number	Aging Temp. °C	Cold Work h	Soln Treat. Time Temp. °C	Quench h	Cond. μm	Grain Size L X T X ST	Hardness Rockwell C	No. of Tests/ Date Pt		
1G	77	27.	570.	T-L	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	2000	NA	200	198.3, V	1
1G	77	50.	570.	T-L	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	2000	NA	200	198.3, V	1
1G	4	41.	621.	T-L	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	2000	NA	200	198.3, V	1
1H	285	25.	559.	T-L	T81	Rolled Plate	19.05	ALCOA; '89 ;103299	NA	NA	NA	2000	NA	100	198.3, V	1
1G	4	51.	621.	T-L	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	2000	NA	200	NA	1
1I	77	24.	624.	T-L	T81	Rolled Plate	19.05	ALCOA; '89 ;103299	NA	NA	NA	2000	NA	100	198.3, V	1
1I	4	38.	670.	T-L	T81	Rolled Plate	19.05	ALCOA; '89 ;103299	NA	NA	NA	2000	NA	100	198.3, V	1
13A	295	22.	469.	T-L	T81	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	*	
36A	295	31.9	NA	T-L	T81	Rolled Plate	12.7	ALCOA ;400-011	NA	NA	NA	NA	NA	NA	1	
11A	298	25.	535.	T-L	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	1	
11A	77	34.	625.	T-L	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	1	
11A	4	39.	705.	T-L	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	1	
1AA	298	24.	548.	T-L	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	1	
36A	295	38.5	NA	45°	T81	Rolled Plate	12.7	ALCOA ;400-011	NA	NA	NA	NA	NA	NA	1	
14A	298	28.	460.	45°	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	1	

Comments from the Al-Li Alloy 2090 Data Table

Reference and  
Note Number

37B--Value reported is a proposed minimum value.

13A--Value reported are "minimum" properties.

Fracture Toughness  
Test Conditions  
Alloy 2090

Ref & Note No.	Specimen Type	Specimen Dimensions			Prestress			Multi-Spec. no/#	Invalidating Criterion	Major Elements wt%				Procedures				
		B	W	a/W	K	Hs	Freq			Li	Cu	Mg	Zr	Si				
1F	CT	12.7	50.6	MA	MA	205	20.	no	no	NA	2.3	2.8	0.1	0.1	NA	0.07	NA	ASTM E813
1F	CT	12.7	50.6	MA	MA	205	20.	no	no	NA	2.3	2.8	0.1	0.1	NA	0.07	NA	ASTM E813
1G	CT	12.7	50.6	MA	MA	76	20.	no	no	NA	2.3	2.7	0.	0.12	NA	0.06	NA	ASTM E813
1H	CT	12.7	50.6	MA	MA	205	20.	no	no	NA	2.3	2.8	0.1	0.1	NA	0.07	NA	ASTM E813
1I	CT	12.7	50.6	MA	MA	76	20.	no	no	NA	2.3	2.8	0.1	0.1	NA	0.07	NA	ASTM E813
11A	CT	MA	MA	MA	MA	MA	MA	MA	MA	NA	2.2	2.7	MA	0.12	NA	NA	NA	ASTM E813-61, E = 79 GPa
12A	CT	MA	MA	MA	MA	MA	MA	MA	MA	NA	MA	MA	MA	MA	NA	NA	NA	*****
13A	CT	MA	MA	MA	MA	MA	MA	MA	MA	NA	2.3*	2.7	0.3	0.12	0.1	0.12	NA	*****
14A	CT	7.6	MA	MA	MA	MA	MA	MA	MA	NA	2.05	2.9	0.03	0.12	E-2	0.02	NA	ASTM E390
36A	CT	MA	MA	MA	MA	MA	MA	MA	MA	NA	MA	MA	MA	MA	NA	NA	NA	*****
36B	CT	MA	MA	MA	MA	MA	MA	MA	MA	NA	MA	MA	MA	MA	NA	NA	NA	*****

Comments from the Al-Li Alloy 2090 Test Conditions Table

Reference and  
Note Number

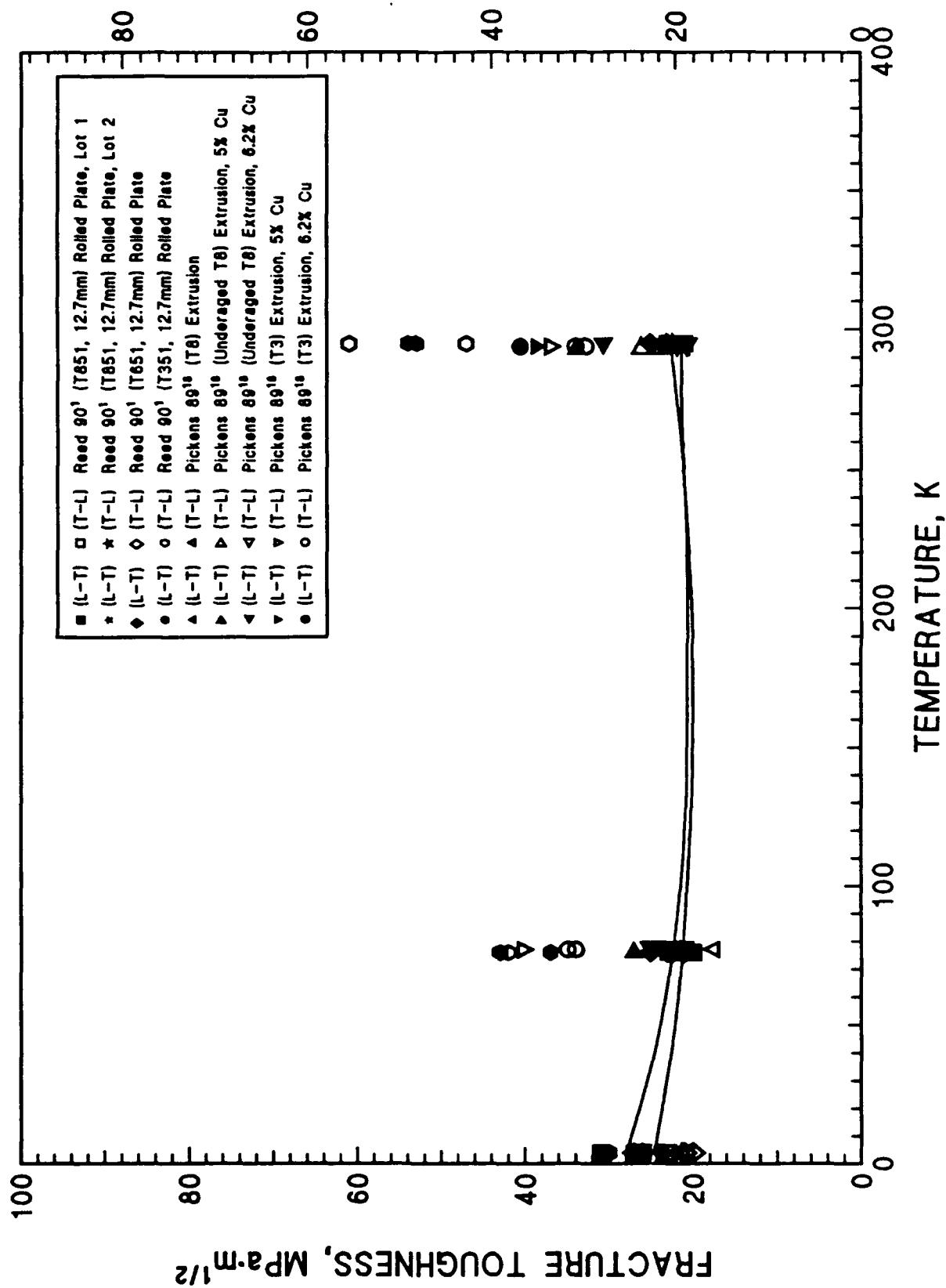
11A--Reported composition is based on nominal values.

13A--Reported composition is the average of the minimum and maximum values.

18A--Reported composition is based on nominal values.

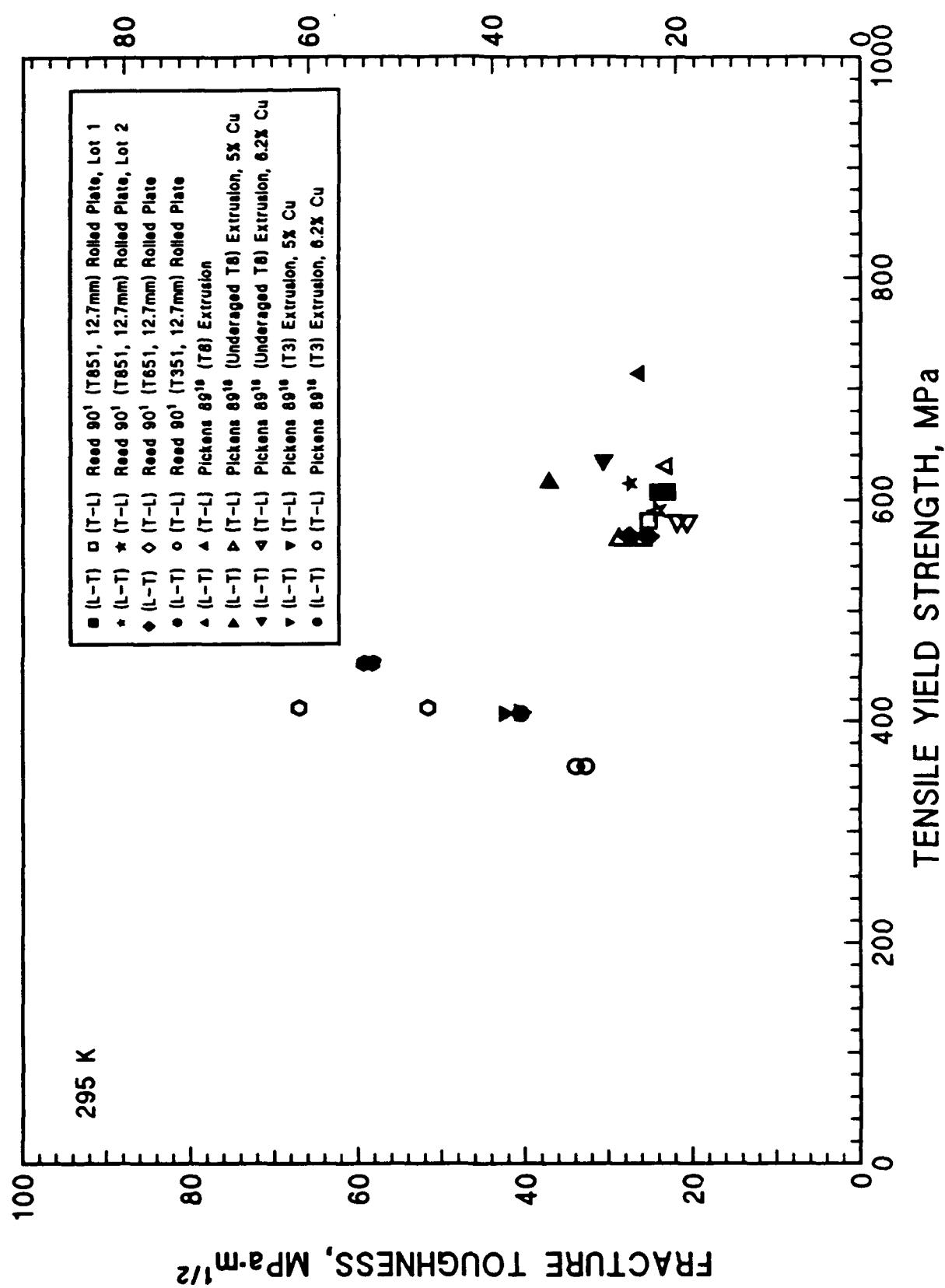
WL049

## FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>

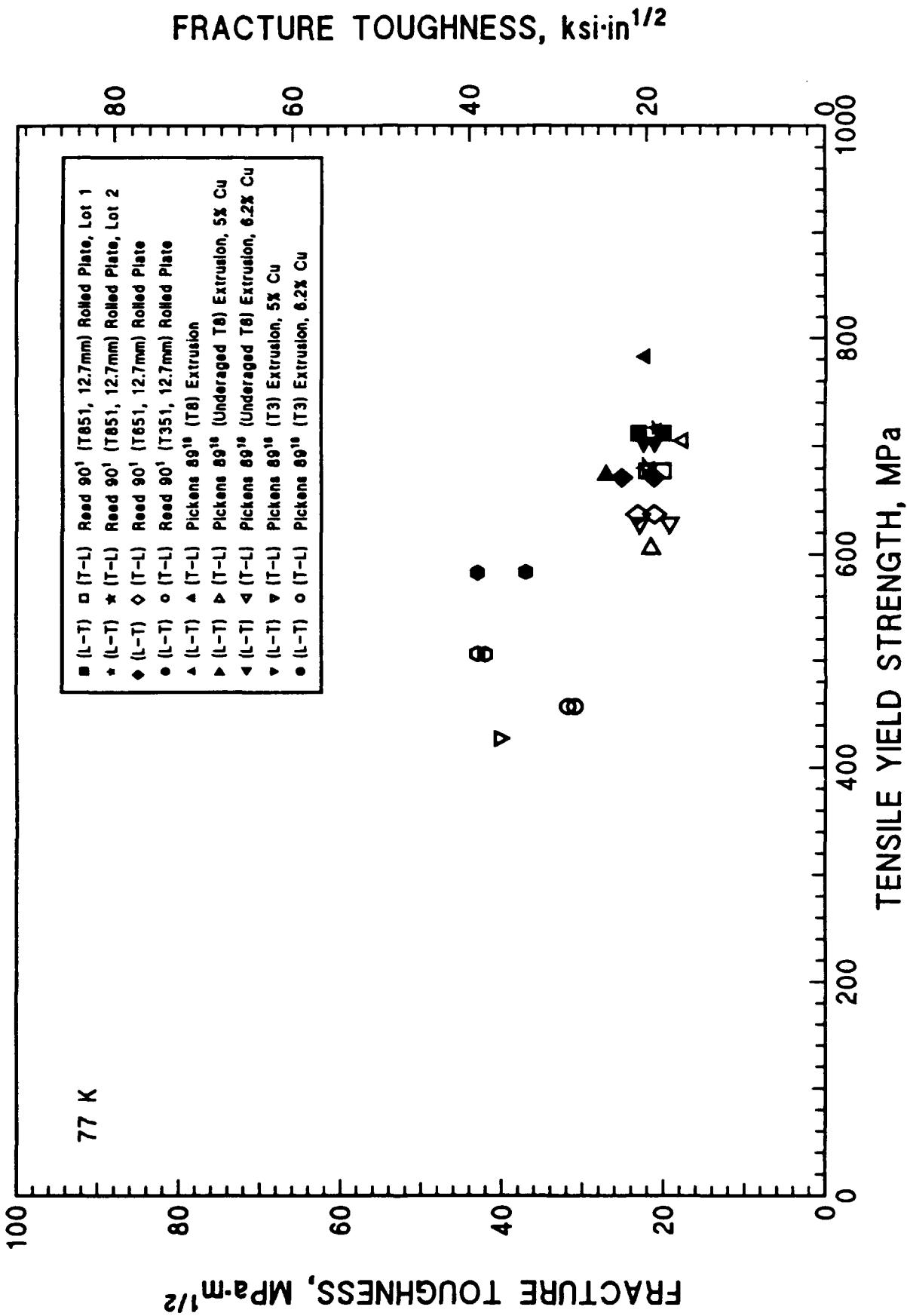


WL049

# FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>

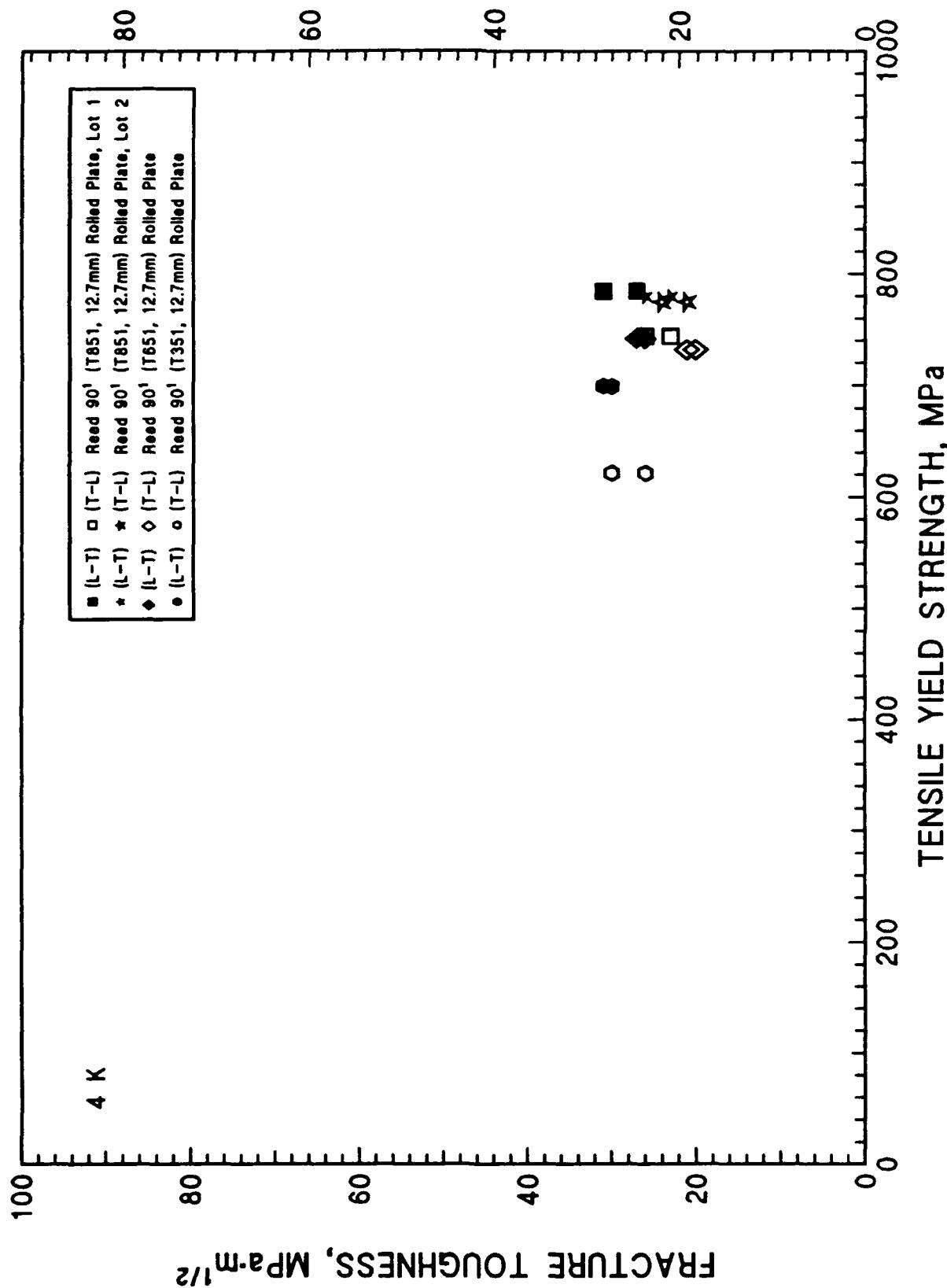


WL049



WL049

FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>



Fracture Toughness  
Alloy WL049

Ref & Note No.	Temp. K	Y.S. MPa/m	Orient. MPa	Temper Form	Product Thickness mm	Supplier; Lot Number	Aging Temp. °C	Cold Work h	Soil Treat. h	Grain Size			No. of Tests/ Date Pt	
										L	X	T	ST	
1J	295	21.	607.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367250A	NA	NA	NA	NA	4000*	1000 NA NA 1
1J	295	22.	607.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367250A	NA	NA	NA	NA	4000*	1000 NA NA 1
1K	76	23.	712.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367250A	NA	NA	NA	NA	4000	1000 NA NA 1
1K	76	20.	712.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367250A	NA	NA	NA	NA	4000*	1000 NA NA 1
1K	4	27.	765.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367250A	NA	NA	NA	NA	4000*	1000 NA NA 1
1K	4	31.	765.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367250A	NA	NA	NA	NA	4000*	1000 NA NA 1
1V	295	25.	615.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367250A	NA	NA	NA	NA	4000*	1000 NA NA 1
1W	4	26.	760.	L-T	T651	Rolled Plate	12.7	Reynolds; '90; 9002311A	NA	NA	NA	NA	4000	1000 NA NA 1
1W	4	23.	760.	L-T	T651	Rolled Plate	12.7	Reynolds; '90; 9002311A	NA	NA	NA	NA	4000	1000 NA NA 1
1W	76	21.	717.	L-T	T651	Rolled Plate	12.7	Reynolds; '90; 9002311A	NA	NA	NA	NA	4000*	1000 NA NA 1
1WA	294	24.	714.	L-T	T6	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA NA 1
16A	77	22.3	763.	L-T	T6	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA NA 1
16B	294	33.8	618.	L-T	UAT6	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA NA 1
16B	77	27.	676.	L-T	UAT6	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA NA 1
16E	77	22.4	701.	L-T	UAT6	Extruded Bar	19.1	M.M. ;NA	NA	NA	NA	NA	NA	NA NA 1
16E	77	21.	701.	L-T	UAT6	Extruded Bar	19.1	M.M. ;NA	NA	NA	NA	NA	NA	NA NA 1
1L	295	25.	567.	L-T	T651	Rolled Plate	12.7	Reynolds; '89; 0367240A	NA	NA	NA	NA	1000	500 NA NA 1

Ref & Note No.	Temp. K	Y.S. MPa/mPa	Orient.	Product Form	Thickness mm	Year; Lot Number	Aging Temp. °C	Work h	Quench °C	Time Cond.	Solv. Treat. L x T x ST μm	Hardness	Grain Size	No. of Tests/ Data Pt	
1L	295	23.	567.	L-T	T651	Rolled Plate	12.7	Reynolds; '89;0367240A	NA	NA	NA	NA	NA	1000 500 NA	1
1M	76	25	671.	L-T	T651	Rolled Plate	12.7	Reynolds; '89;0367240A	NA	NA	NA	NA	NA	1000 500 NA	1
1N	76	21.	671.	L-T	T651	Rolled Plate	12.7	Reynolds; '89;0367240A	NA	NA	NA	NA	NA	1000 500 NA	1
1M	4	26.	742.	L-T	T651	Rolled Plate	12.7	Reynolds; '89;0367240A	NA	NA	NA	NA	NA	1000 500 NA	1
1M	4	27.	742.	L-T	T651	Rolled Plate	12.7	Reynolds; '89;0367240A	NA	NA	NA	NA	NA	1000 500 NA	1
1N	295	53.	453.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0367230A	NA	NA	NA	NA	NA	600 400 NA	1
1N	295	54.	453.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0367230A	NA	NA	NA	NA	NA	600 400 NA	1
10	77	37.	563.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0367230A	NA	NA	NA	NA	NA	600 400 NA	1
10	76	43.	563.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0367230A	NA	NA	NA	NA	NA	600 400 NA	1
10	4	30.	669.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0367230A	NA	NA	NA	NA	NA	600 400 NA	1
10	4	31.	669.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0367230A	NA	NA	NA	NA	NA	600 400 NA	1
10C	294	30.7	407.	L-T	T3	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA	1
18D	294	36.9	407.	L-T	T3	Extruded Bar	19.1	M.M. ;NA	NA	NA	NA	NA	NA	NA	1
1J	295	23.	561.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0367250A	NA	NA	NA	NA	NA	4000+ 1000 NA	1
1J	295	23.	561.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0367250A	NA	NA	NA	NA	NA	4000+ 1000 NA	1
1K	76	22.	677.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0367250A	NA	NA	NA	NA	NA	4000+ 1000 NA	1
1K	76	20.	677.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0367250A	NA	NA	NA	NA	NA	4000+ 1000 NA	1
1K	4	26.	744.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0367250A	NA	NA	NA	NA	NA	4000+ 1000 NA	1
1K	4	23.	744.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0367250A	NA	NA	NA	NA	NA	4000+ 1000 NA	1

Ref. No.	Temp. K	K MPa/m	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier: Lot Number	Aging Temp. °C	Cold Work h	Soln. Treat. Cond. h	Grain Size μm	Hardness L X T X ST	No. of Tests/ Date Pt.
IV 285	22.	580.	T-L	T651	Rolled Plate	12.7	Reynolds: '90; 900Z31A	NA NA NA	NA	NA	NA	4000*	1000 NA NA	1
IW 4	24.	775.	T-L	T651	Rolled Plate	12.7	Reynolds: '90; 900Z31A	NA NA NA	NA	NA	NA	4000	1000 NA NA	1
IW 76	22.	680.	T-L	T651	Rolled Plate	12.7	Reynolds: '90; 900Z31A	NA NA NA	NA	NA	NA	4000*	1000 NA NA	1
IW 4	21.	775.	T-L	T651	Rolled Plate	12.7	Reynolds: '90; 900Z31A	NA NA NA	NA	NA	NA	4000*	1000 NA NA	1
16A 294	21.	630.	T-L	T6	Extruded Bar	19.05	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
16A 77	17.5	705.	T-L	T6	Extruded Bar	19.05	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
16B 294	26.2	566.	T-L	UAT6	Extruded Bar	19.05	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
16B 294	23.7	566.	T-L	UAT6	Extruded Bar	19.05	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
16B 77	21.5	607.	T-L	UAT6	Extruded Bar	19.05	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
16E 294	18.6	579.	T-L	UAT6	Extruded Bar	19.1	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
16E 294	19.9	579.	T-L	UAT6	Extruded Bar	19.1	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
16E 77	22.9	627.	T-L	UAT6	Extruded Bar	19.1	M.M. ;NA	NA NA NA	NA	NA	NA	NA	NA NA NA	1
1M 76	21.	637.	T-L	T651	Rolled Plate	12.7	Reynolds: '89; 0387240A	NA NA NA	NA	NA	NA	1000	500 NA NA	1
1M 76	23.	637.	T-L	T651	Rolled Plate	12.7	Reynolds: '89; 0387240A	NA NA NA	NA	NA	NA	1000	500 NA NA	1
1M 4	21.	732.	T-L	T651	Rolled Plate	12.7	Reynolds: '89; 0387240A	NA NA NA	NA	NA	NA	1000	500 NA NA	1
1N 295	61.	412.	T-L	T351	Rolled Plate	12.7	Reynolds: '89; 0387230A	NA NA NA	NA	NA	NA	800	400 NA NA	1
1N 295	47.	412.	T-L	T351	Rolled Plate	12.7	Reynolds: '89; 0387230A	NA NA NA	NA	NA	NA	800	400 NA NA	1

Ref & Note No.	Temp. K	Y.S. MPa/m	Orient. MPa/m	Temper Form	Product Thickness mm	Supplier; Year; Lot Number	Aging Temp. °C	Cold Work h	Quench °C	Temp. °C	Time h	Cond. μm	L X T X ST μm	Hardness	Grain Size μm	No. of Tests/ Data Pt.
10	77	43.	506.	T-L	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	1
10	76	42.	506.	T-L	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	1
10	4	26.	621.	T-L	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	1
10	4	30.	621.	T-L	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	1
18C	294	37.7	406.	T-L	T3	Extruded Bar	19.05	M.M.	NA	NA	NA	NA	NA	NA	NA	1
18C	77	40.3	427.	T-L	T3	Extruded Bar	10.05	M.M.	NA	NA	NA	NA	NA	NA	NA	1
18D	294	29.8	359.	T-L	T3	Extruded Bar	19.1	M.M.	NA	NA	NA	NA	NA	NA	NA	1
18D	294	30.9	359.	T-L	T3	Extruded Bar	19.1	M.M.	NA	NA	NA	NA	NA	NA	NA	1
18D	77	31.8	457.	T-L	T3	Extruded Bar	19.1	M.M.	NA	NA	NA	NA	NA	NA	NA	1
18D	77	30.9	457.	T-L	T3	Extruded Bar	19.1	M.M.	NA	NA	NA	NA	NA	NA	NA	1

Comments from the Al-Li Alloy WL049 Data Table

Reference and  
Note Number

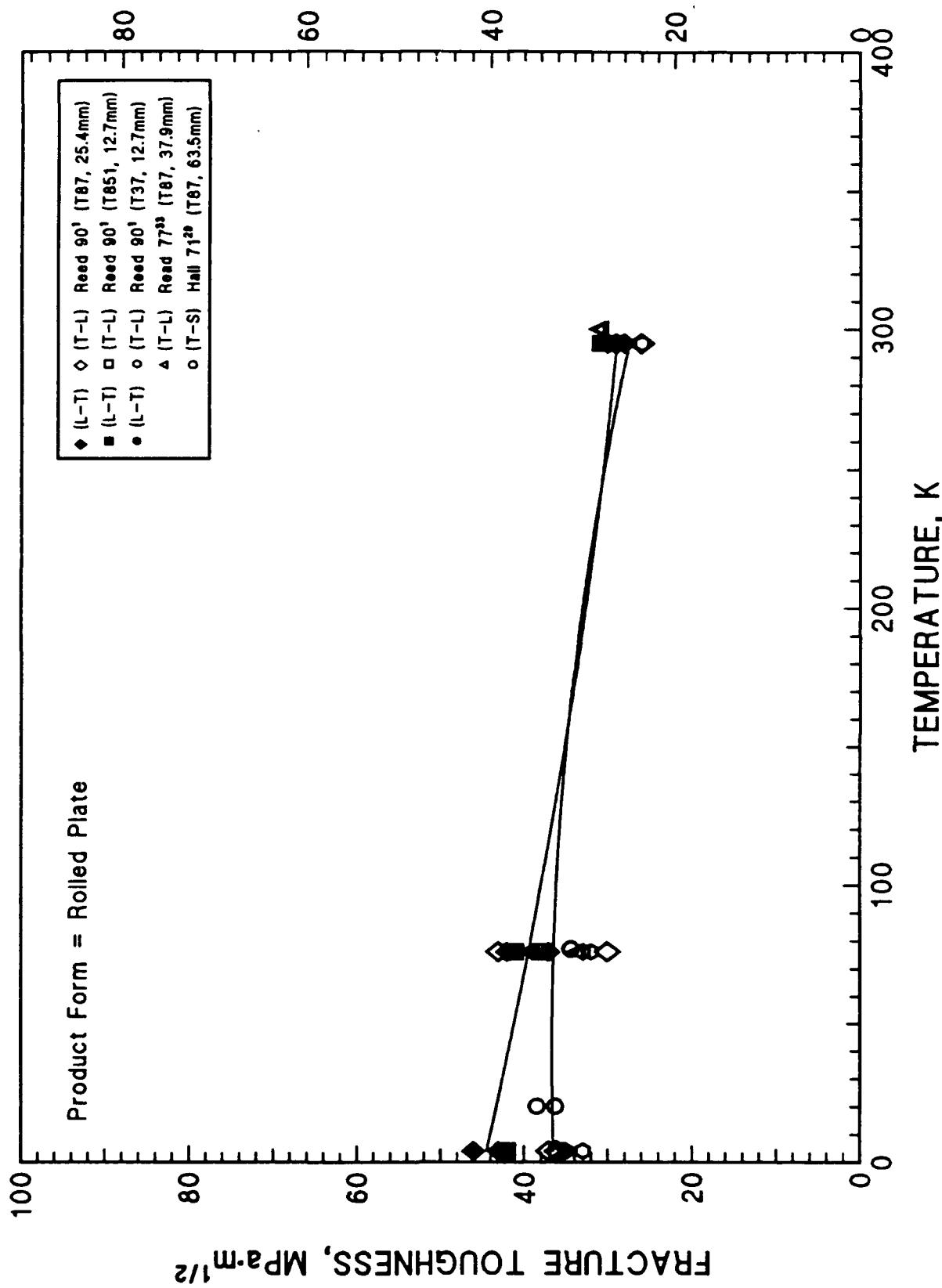
1J-K--Values reported are the average of the range of grain sizes.

18A-E--Under the supplier column, M.M. = Martin Marietta.

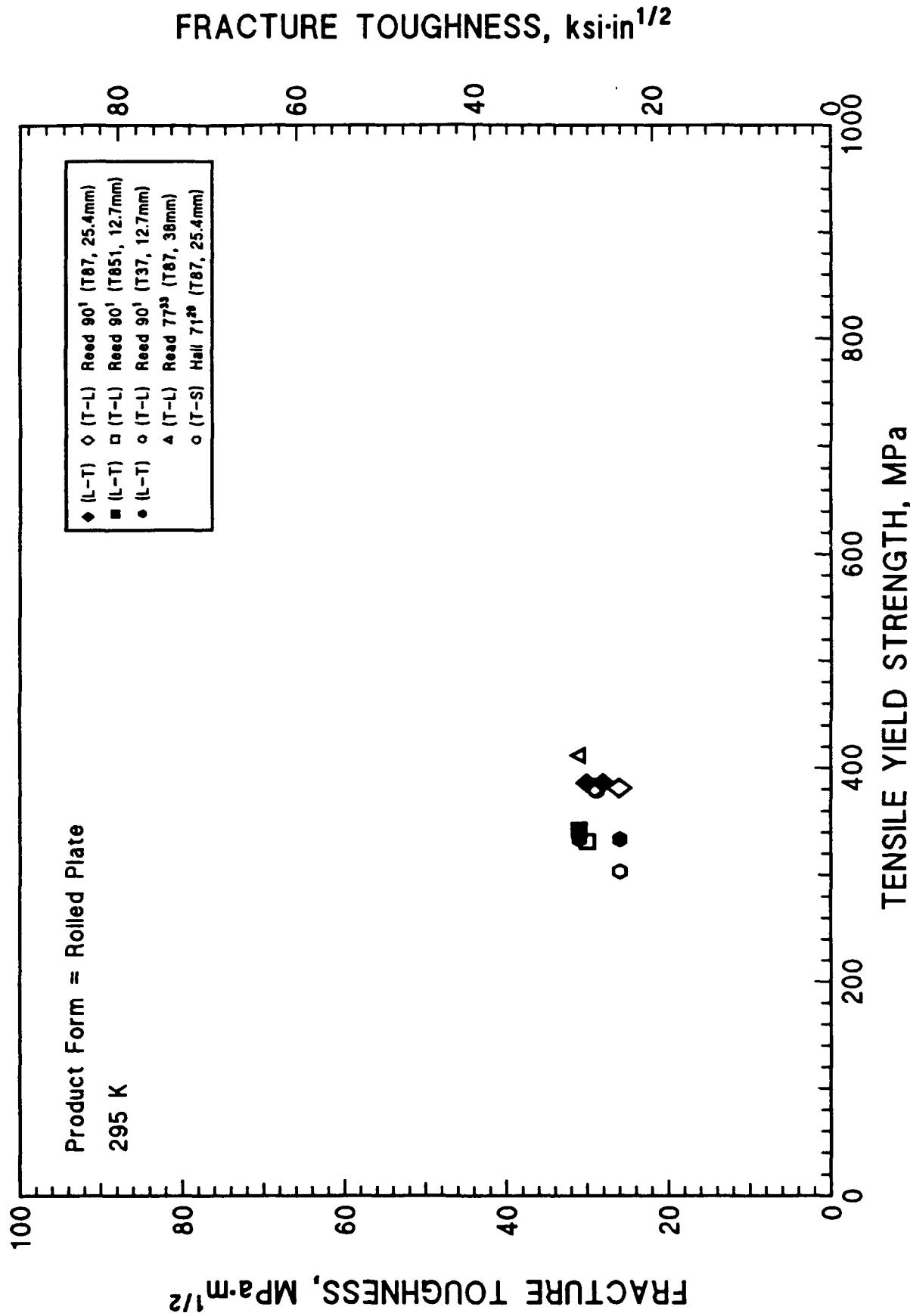
Fracture Toughness  
Test Conditions  
Alloy WL049

Ref & No.	Specimen Type	Specimen Dimensions				Prestress K	Temp Hz	Side- Groove no./#	Multi- Spec. no./#	Invalidating Criterion	Major Elements				A4	Procedures		
		B mm	W mm	a/W	Other						L <sub>i</sub>	Cu	Mg	Zr	Si			
1J	CT	12.7	50.8	MA	NA	295	20.	no	no	NA	0.38	4.7	0.4	0.12	0.02	0.03	0.37	ASTM E613
1K	CT	12.7	50.8	MA	NA	76	20.	no	no	NA	0.38	4.7	0.4	0.12	0.02	0.03	0.37	ASTM E613
1L	CT	12.7	50.8	MA	NA	295	20.	no	no	NA	1.26	4.7	0.4	0.12	0.02	0.03	0.35	ASTM E613
1M	CT	12.7	50.8	MA	NA	76	20.	no	no	NA	1.26	4.7	0.4	0.12	0.02	0.03	0.35	ASTM E613
1N	CT	12.7	50.8	MA	NA	295	20.	no	no	NA	1.26	4.7	0.4	0.12	0.02	0.03	0.35	ASTM E613
1O	CT	12.7	50.8	MA	NA	76	20.	no	no	NA	1.26	4.7	0.4	0.12	0.02	0.03	MA	ASTM E613
1OA	CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.3	5.	0.4	0.14	NA	NA	0.4	ASTM E399
1OB	CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.3	5.	0.4	0.14	NA	NA	0.4	ASTM E399
1OC	CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.3	5.	0.4	0.14	NA	NA	0.4	ASTM E399
1OD	CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.4	6.2	0.4	0.14	NA	NA	0.4	ASTM E399
1OE	CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.4	6.2	0.4	0.14	NA	NA	0.4	ASTM E399

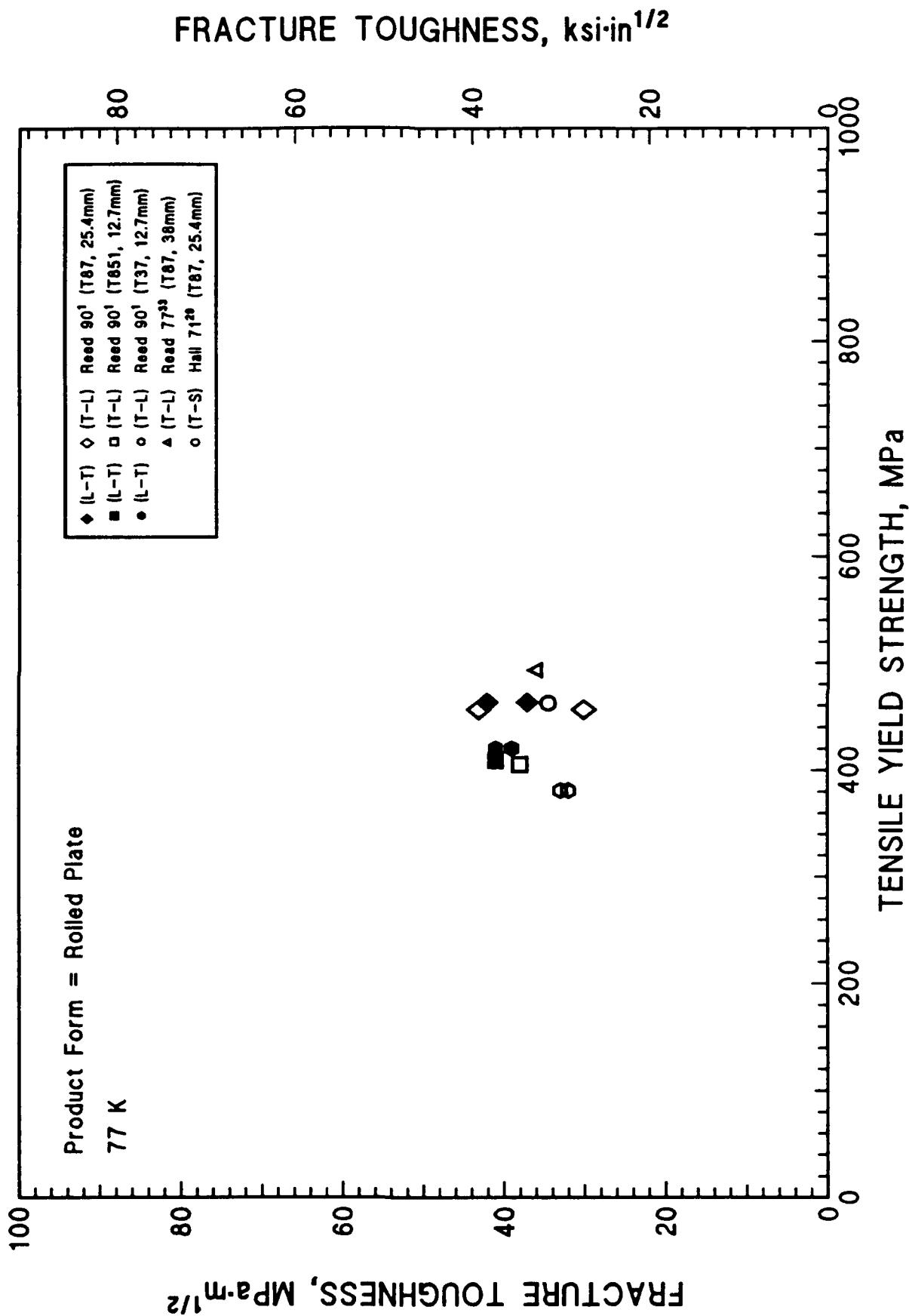
2219

FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>

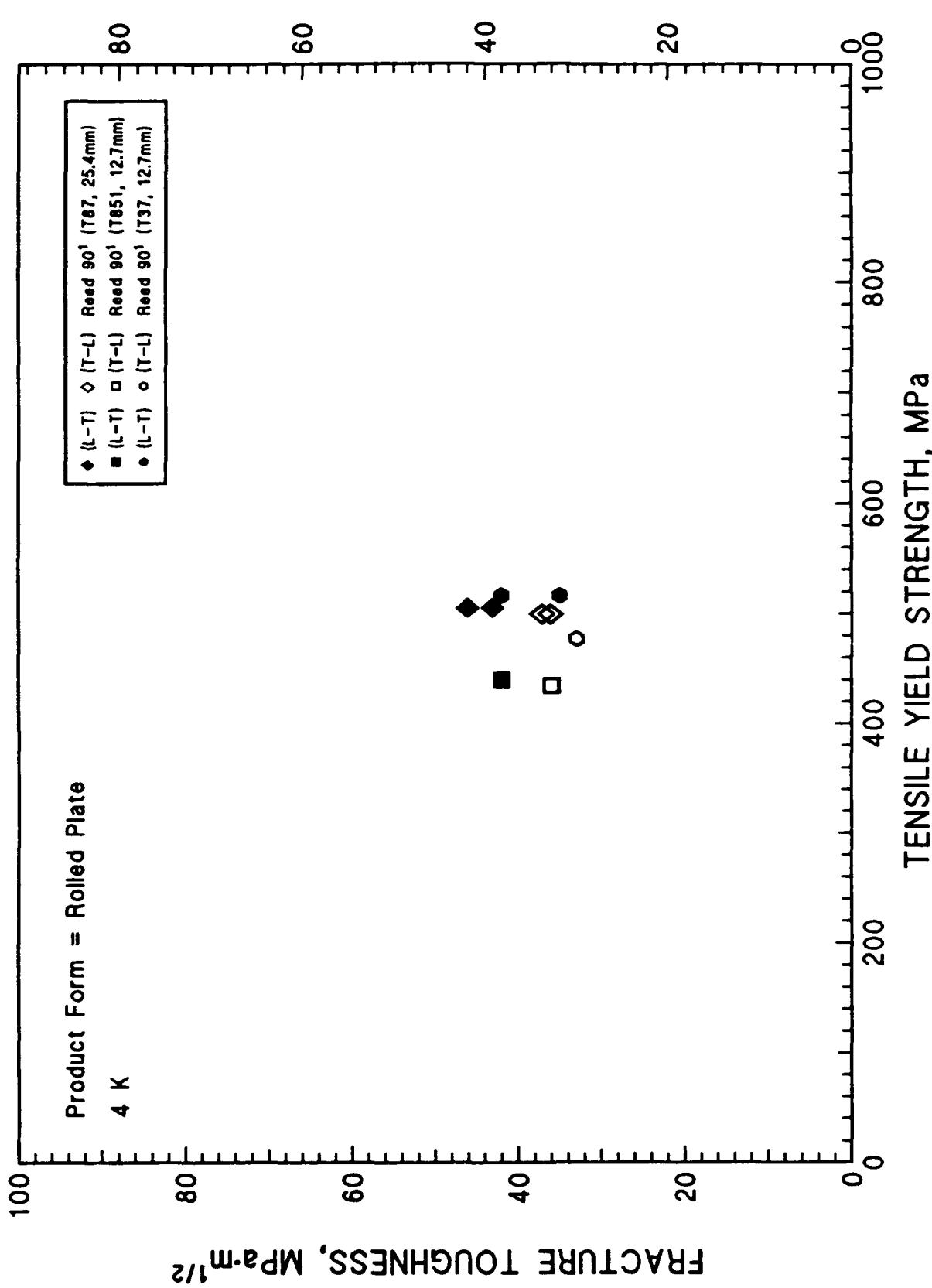
2219



2219



2219

FRACTURE TOUGHNESS, ksi·in<sup>1/2</sup>

Fracture Toughness  
Alloy 2219

Ref & Note No.	Temp. K	Y.S. MPa/m	Orient.	Temper Form	Product Thickness mm	Supplier: Lot Number	Aging Temp. °C	Cold Work h	Soil Treat. Time h	Grain Size			No. of Tests/ Data Pt.					
										L	X	T	X	ST				
1P	295	30.	366.	L-T	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1P	295	28.	366.	L-T	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	77	42.	463.	L-T	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	77	37.	463.	L-T	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	4	46.	505.	L-T	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	4	43.	505.	L-T	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1R	295	31.	342.	L-T	T851	Rolled Plate	12.7	Kaiser; '89 ;429881	NA	NA	NA	NA	NA	175	NA	50	154.8	V
1S	76	41.	409.	L-T	T851	Rolled Plate	12.7	Kaiser; '89 ;429881	NA	NA	NA	NA	NA	175	NA	50	154.8	V
1S	4	42.	439.	L-T	T851	Rolled Plate	12.7	Kaiser; '89 ;429881	NA	NA	NA	NA	NA	175	NA	50	154.8	V
1T	295	26.	333.	L-T	T37	Rolled Plate	12.7	Kaiser; '89 ;466341	NA	NA	NA	NA	NA	175	NA	50	142.9	V
1T	295	31.	333.	L-T	T37	Rolled Plate	12.7	Kaiser; '89 ;466342	NA	NA	NA	NA	NA	175	NA	50	142.9	V
1U	76	39.	420.	L-T	T37	Rolled Plate	12.7	Kaiser; '89 ;466341	NA	NA	NA	NA	NA	175	NA	50	142.9	V
1U	76	41.	420.	L-T	T37	Rolled Plate	12.7	Kaiser; '89 ;466342	NA	NA	NA	NA	NA	175	NA	50	142.9	V
1U	4	42.	516.	L-T	T37	Rolled Plate	12.7	Kaiser; '89 ;466342	NA	NA	NA	NA	NA	175	NA	50	142.9	V
1P	295	26.	361.	T-L	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1P	295	29.	381.	T-L	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	76	43.	456.	T-L	T87	Rolled Plate	25.4	NASA; '90 ;464681	NA	NA	NA	NA	NA	300	50	NA	NA	1

Ref & Note No.	Temp. K	Y.S. MPa	Orient.	Product Form	Product Thickness mm	Supplier; Lot Number	Aging Temp. °C	Cold Work h	Time Quench h	Soln Treat. Cond.	Grain Size μm	No. of Tests/ Date Pt
1Q 76 30. 456. T-L T67	Rolled Plate	25.4 NASA: '90 :464661	NA NA NA	NA	300 50 MA	NA	300	50	NA	NA	1	
1Q 4 37. 499. T-L T67	Rolled Plate	25.4 NASA: '90 :464661	NA NA NA	NA	300 50 MA	NA	300	50	NA	NA	1	
1Q 4 36. 499. T-L T67	Rolled Plate	25.4 NASA: '90 :464661	NA NA NA	NA	300 50 MA	NA	300	50	NA	NA	1	
33A 300 30.6 412. T-L T67	Rolled Plate	36. NASA: '90 :429981	NA NA NA	NA	3000 50 MA	NA	3000	50	MA	NA	1	
33A 300 31. 412. T-L T67	Rolled Plate	36. NASA: '90 :429981	NA NA NA	NA	3000 50 MA	NA	3000	50	MA	NA	1	
33A 76 33.5 493. T-L T67	Rolled Plate	36. NASA: '90 :429981	NA NA NA	NA	3000 50 MA	NA	3000	50	MA	NA	1	
33A 76 37.2 493. T-L T67	Rolled Plate	36. NASA: '90 :429981	NA NA NA	NA	3000 50 MA	NA	3000	50	MA	NA	1	
1R 295 30. 331. T-L T651	Rolled Plate	12.7 Kaiser: '89 :429981	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
1S 76 36. 405. T-L T651	Rolled Plate	12.7 Kaiser: '89 :429981	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
1S 4 36. 436. T-L T651	Rolled Plate	12.7 Kaiser: '89 :429981	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
1T 295 26. 303. T-L T37	Rolled Plate	12.7 Kaiser: '89 :466341	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
1T 295 26. 303. T-L T37	Rolled Plate	12.7 Kaiser: '89 :466342	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
1U 76 32. 381. T-L T37	Rolled Plate	12.7 Kaiser: '89 :466342	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
1U 76 33. 381. T-L T37	Rolled Plate	12.7 Kaiser: '89 :466342	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
1U 4 33. 477. T-L T37	Rolled Plate	12.7 Kaiser: '89 :466342	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
20A 295 29. 379. T-S T67	Rolled Plate	63.5 NASA: '90 :466342	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
20A 295 28.7 379. T-S T67	Rolled Plate	63.5 NASA: '90 :466342	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	
20A 77 34.5 462. T-S T67	Rolled Plate	63.5 NASA: '90 :466342	NA NA NA	NA	NA	NA	NA	NA	NA	NA	1	

Ref & Note No.	Temp. K	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier; Year; Lot Number	Aging Temp. °C	Cold Work Time h	Solv Treat. Temp. °C	Quench Time h	Cond. L X T X SR μm	Grain Size			Hardness	Tests / Data Pt.	No. of Tests / Data Pt.
													L	X	T			
29A	77	36.4	462.	T-3	T67	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
29A	20	36.3	503.	T-3	T67	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
29A	20	36.5	503.	T-3	T67	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	

Fracture Toughness  
Test Conditions  
Alloy 2219

Ref #	Note No.	Specimen Type	Specimen Dimensions				Prestress Temp K	Freq Hz	Side-Groove	Multi-Spec. no./#	Invalidating Criterion	Major Elements wt%				Procedures			
			B	W	a/W	Other mm						L <sub>1</sub>	Cu	Hg	Zr	S <sub>1</sub>			
6P	CT	12.7	50.8	NA	NA		295	20.	no	no	NA	NA	5.7	NA	0.15	0.07	0.02	MA	ASTM E613
6Q	CT	12.7	50.8	NA	NA		76	20.	no	no	NA	NA	5.7	NA	0.15	0.07	0.02	MA	ASTM E613
6R	CT	12.7	50.8	NA	NA		295	20.	no	no	NA	NA	5.7	NA	0.08	0.04	0.02	MA	ASTM E613
6S	CT	12.7	50.8	NA	NA		76	20.	no	no	NA	NA	5.7	NA	0.08	0.04	0.02	MA	ASTM E613
6T	CT	12.7	50.8	NA	NA		295	20.	no	no	NA	NA	5.7	NA	0.03	0.04	0.02	MA	ASTM E613
6U	CT	12.7	50.8	NA	NA		76	20.	no	no	NA	NA	5.7	NA	0.03	0.04	0.02	MA	ASTM E613
29A	CT	31.6	50.8	NA	NA		295	NA	no	no	NA	NA	6.3	NA	0.18	0.2	0.3	MA	ASTM E399-70T
33A	CT	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	6.4	NA	0.16	0.15	0.2	MA	ASTM E399-74

### 3. ELASTIC CONSTANTS

#### 3.1. Introduction to Graphs

##### 3.1.1. Temperature Dependence

Cryogenic elastic constant data are available only for 2090-T81 (Young's modulus, E, and Poisson's ratio,  $\nu$ ) and 2219-T87 (E,  $\nu$ , bulk modulus, B, and shear modulus, G). These data are presented as a functions of temperature in four graphs and a table following this discussion. The reason that different values of E (77.7 and 74.7 GPa) were obtained for 2219-T87 at ambient temperature in the same laboratory is not understood. It is likely that the values reported in the earlier measurements are too systematically too high, but the temperature dependence has not been remeasured. (A later measurement at room temperature gave a value of 74.8 GPa.) The value given in MIL-HNBK-5E<sup>2</sup> for E for alloy 2219 plate is 72.4 GPa. There is considerable disagreement in the literature about the correct value of E at ambient temperature for pure Al and therefore, for Al alloyed with small ( $\leq 5\%$ ) amounts of other elements (see Section 3.1.2. below). Because there is so much uncertainty in the literature, and because so little cryogenic data are available, a table of ambient-temperature values of elastic constants from various sources for the Al-Li alloys 8090, 2090, and WL049, and alloy 2219 follows the presentation of the cryogenic data. After a value of E at ambient temperature is chosen, the following equation may be used to estimate values for  $4 \text{ K} \leq T \leq 295 \text{ K}$ :

$$E(T) = E(295 \text{ K}) [1.1 + 1.2 \times 10^{-4}T - 4.0 \times 10^{-6}T^2 + 1.1 \times 10^{-8}T^3 - 1.2 \times 10^{-11}T^4] \quad (1)$$

Values derived from Equation (1) should be used with caution because it is based on the one set of measurements available for 2090.<sup>37</sup>

##### 3.1.2. Effects of Alloying Elements, Cold Work, and Other Factors

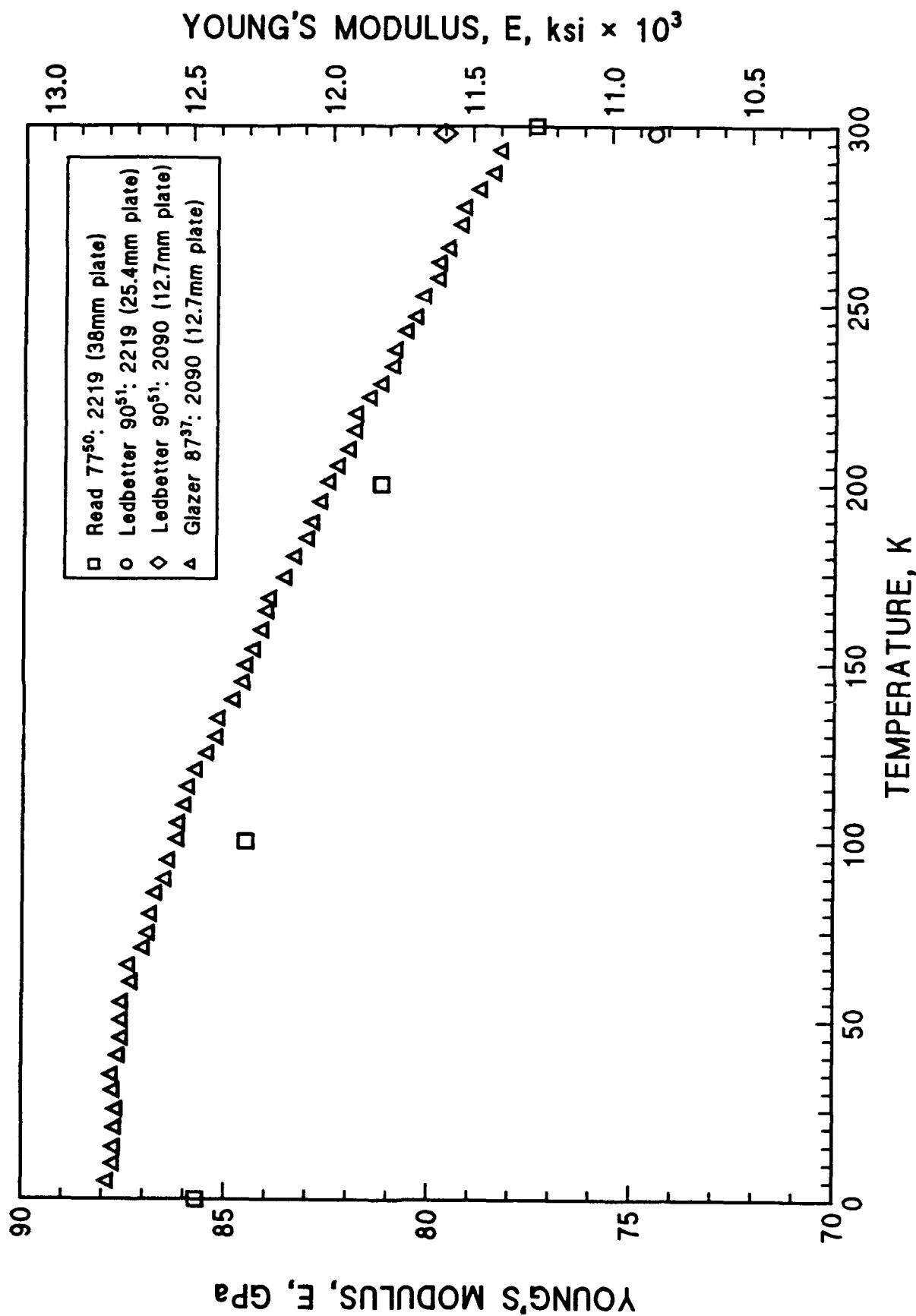
Several sets of static measurements are available on the increase in E with alloying additions of Li;<sup>38,39</sup> Li and Mg;<sup>38</sup> and Li and Cu.<sup>39</sup> References 38 and 39 give 66 and 62 GPa, respectively, as the ambient temperature value of E for high purity Al. Measured values of E for Al-2%Li were 79 GPa<sup>38</sup> and 73 GPa.<sup>39</sup> E was found to be 82 GPa<sup>39</sup> for Al-2024-2%Li. The composition of Al-alloy 2024 (4.5Cu, 1.5Mg, 0.6Mn) is very similar to the composition of Al-alloy 2219 (5.8-6.8Cu, 0.2-0.4Mn). However, values of E for pure Al in the literature derived from the single crystal elastic constants measured by dynamic methods are usually about 10% higher than the values in these two references,<sup>38,39</sup> averaging around 70 to 72 GPa. (Values of Al-Li and Al-Cu-Li alloys would be expected to be correspondingly higher.) Reed<sup>40</sup> presents a table of Al single-crystal elastic constants from several sources and uses the average of these constants to calculate an E of 70.4 GPa. The calculation is based on a formula presented by Hill<sup>41</sup> in the early 1950s. The discrepancy between values calculated from single-crystal elastic constants using the Hill formula and static measurements of Noble<sup>38</sup> was noted by Muller et al.,<sup>42</sup> but the explanation advanced, microplasticity, may not be sufficient to explain such a large disparity in the values. To validate his formula, Hill used a set of measurements on elastic constants of four common elements (including Al) whose origin is not well-documented. Several dynamic measurements<sup>43,44,45</sup> not based

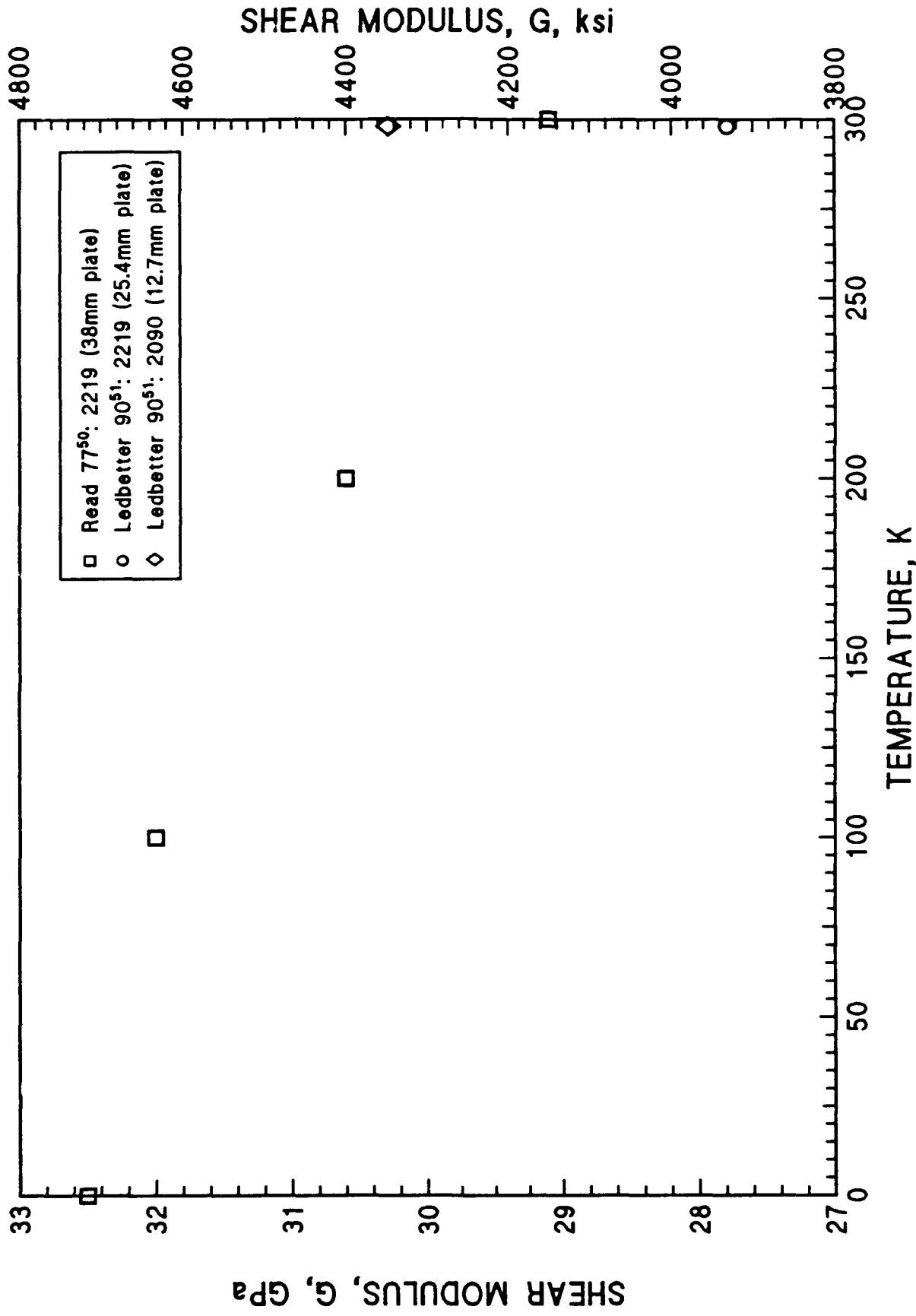
on single-crystal elastic constants and the Hill formula give about 70 GPa for E of pure Al. This disagrees with values of 66, 64, and 65 GPa obtained by static measurements<sup>46</sup> on commercially pure Al (99.5%) as well as the values quoted above,<sup>38,39</sup> which are also derived from static measurements.

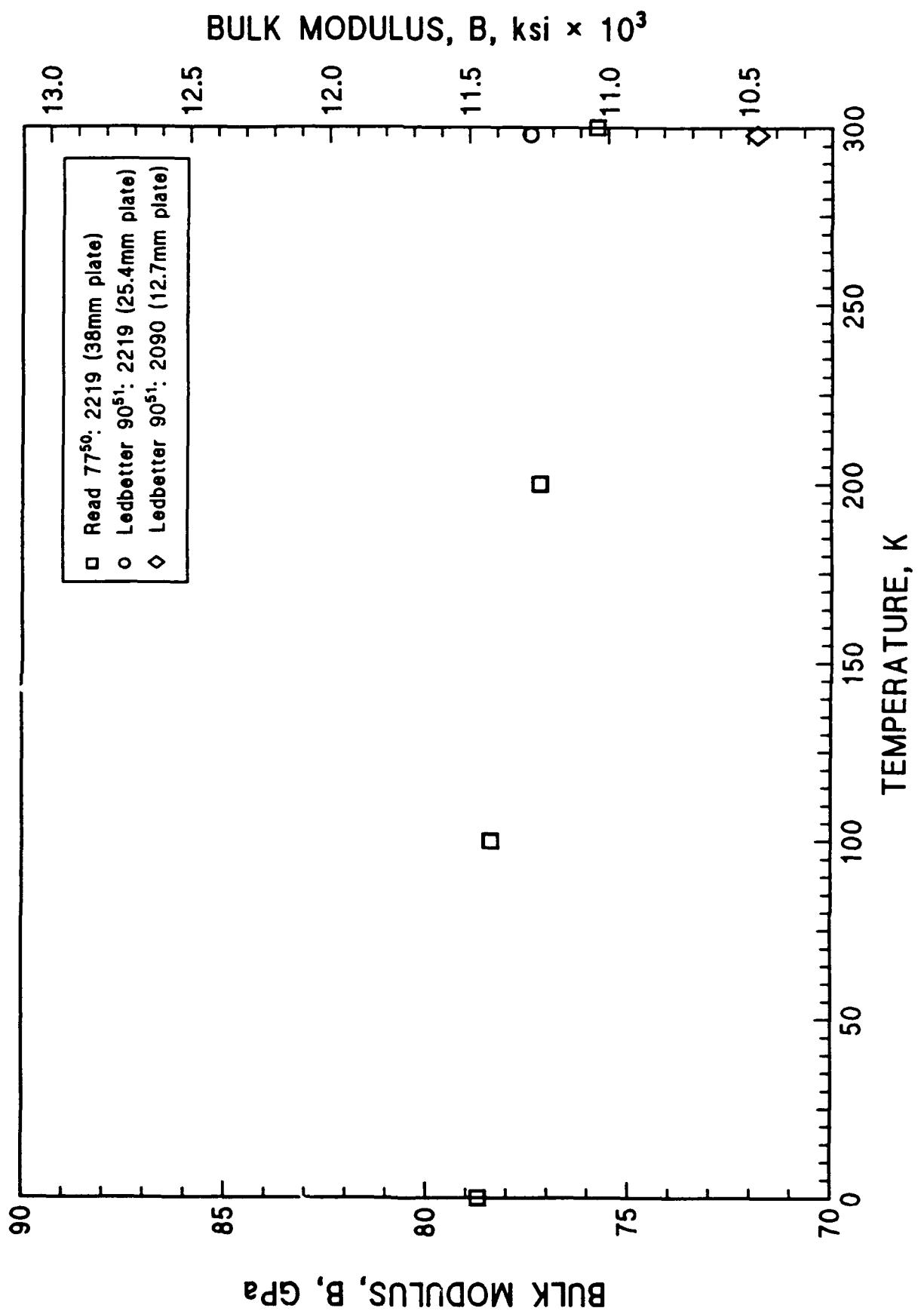
Differences between static and dynamic measurements should be only about a percent,<sup>47</sup> and so the discrepancy should not be attributable to dissimilar measurement techniques. The Hill formula is frequently employed in the literature of basic science to calculate polycrystalline elastic constant values from single-crystal measurements. However, to our knowledge, it has not been tested against carefully evaluated measurements on polycrystalline specimens of a wide variety of elements. Furthermore, the disagreement of predicted values of E with static measurements (commonly used in the aerospace industry) has not been widely recognized.

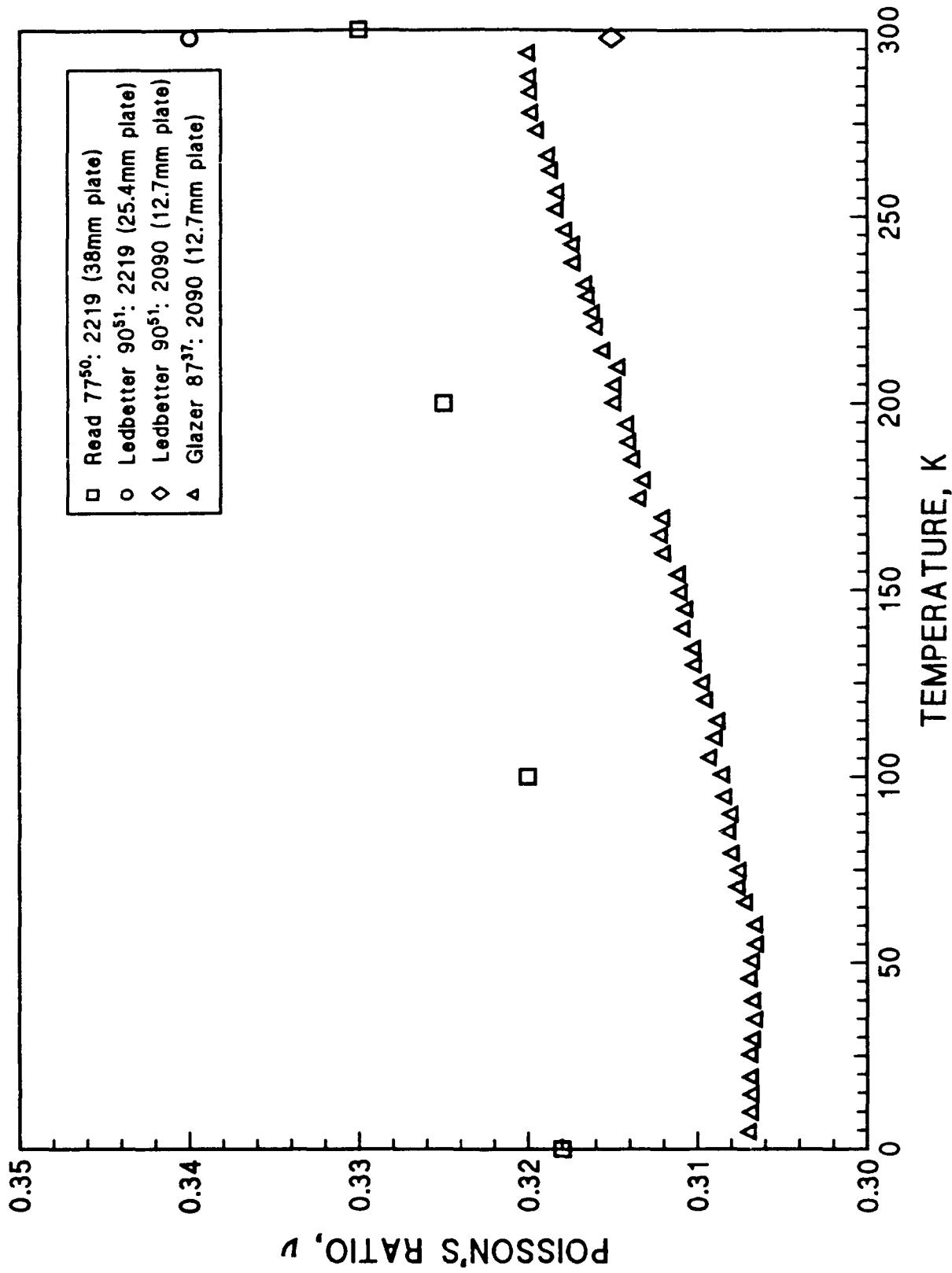
A calculation by Wawra<sup>48</sup> for Al gives a directional dependence for E of pure Al, such that  $E_{111} = 73.8$  GPa and  $E_{100} = 63.2$  GPa, which is approximately the size of the discrepancy in the measurements. Most polycrystalline Al is probably not strongly textured, however, and texture has not been reported with the measurements of E. Warwa<sup>48</sup> also reports a decrease of E of up to  $\approx 3\%$  over a range of cold work from 0 to 100%. Decreasing the purity of the Al from 99.99 to 99.6% increased E<sup>48</sup> by about 3% to a value of 72.8 GPa. These latter effects do not appear large enough to explain the discrepancy.

Varying the aging time of Al-Li alloys also has an effect on E.<sup>49</sup> Effects were less than 2% for aging temperature of 230, 210, and 190 °C with aging times of up to 1000 h. This work was carried out on a binary Al-2.5wt%Li alloy using an ultrasonic measurement technique. Another recent paper<sup>47</sup> also presents results of aging treatment and specimen thickness on E and other elastic constants of 2090-T8E50 as a function of the angle from rolling direction. Effects again are small,  $\approx 2-3\%$ , but the anisotropy in E can be as much as 6% at 45° from the rolling direction.









Density and Elastic Constants of Al-Li Alloys and Alloy 2219 at Ambient Temperature.

Alloy	Density, kg/m <sup>3</sup> x 10 <sup>3</sup>	Young's Modulus, E, GPa	Shear Modulus, G, GPa	Bulk Modulus, B, GPa	Poisson's Ratio, $\nu$	Ref. No.	Method of Analysis
8090-T8771	--	79.3	--	--	0.292	5	1
2090-T81	2.60	79.65	30.28	71.83	0.3152	51	2
2090-T81	2.59	78.28	29.65	72.56	0.320	37	2
2090-T8E50	--	78.60	--	--	--	47	2
2090-T83	--	73.3	--	--	0.35	36	1
WL049-T851	2.71	76.60	28.83	74.46	0.3285	51	2
WL049-T851	2.70	77.9	--	--	--	52	2
2219-T87	2.82	74.46	27.79	77.45	0.3398	51	2
2219-T87	--	77.4	29.1	75.8	0.330	33	2

1 Static measurement.

2 Dynamic measurement.

Elastic Constants of Al-Li Alloys and Alloy 2219 at Low Temperatures.

Alloy	Temp., K	Young's Modulus, E, GPa	Shear Modulus, G, GPa	Bulk Modulus, B, GPa	Poisson's Ratio, $\nu$	Ref. No.	Method of Analysis
2219	0	85.7	32.5	78.7	0.318	50	2
	100	84.5	32.0	78.4	0.320	50	2
	200	81.2	30.6	77.2	0.325	50	2
	300	77.4	29.1	75.8	0.330	50	2
2219	298	74.5	27.8	77.5	0.340	51	2
2090	298	79.7	30.3	71.8	0.315	51	2
2090	5	87.8	--	--	0.307	37	2
	10	87.7	--	--	0.307	37	2
	15	87.7	--	--	0.307	37	2
	20	87.7	--	--	0.307	37	2
	25	87.6	--	--	0.307	37	2
	30	87.7	--	--	0.307	37	2
	35	87.7	--	--	0.306	37	2
	40	87.6	--	--	0.307	37	2
	45	87.5	--	--	0.307	37	2
	50	87.5	--	--	0.307	37	2
	55	87.5	--	--	0.306	37	2
	60	87.3	--	--	0.306	37	2
	65	87.3	--	--	0.307	37	2
	70	87.0	--	--	0.307	37	2
	75	86.9	--	--	0.307	37	2
	80	86.8	--	--	0.308	37	2
	85	86.7	--	--	0.308	37	2
	90	86.5	--	--	0.308	37	2
	95	86.4	--	--	0.308	37	2
	100	86.1	--	--	0.308	37	2
	105	86.1	--	--	0.309	37	2
	110	86.0	--	--	0.309	37	2
	115	85.9	--	--	0.309	37	2
	120	85.7	--	--	0.309	37	2
	125	85.4	--	--	0.310	37	2
	130	85.2	--	--	0.310	37	2
	135	85.2	--	--	0.310	37	2
	140	84.8	--	--	0.311	37	2
	145	84.5	--	--	0.311	37	2
	150	84.5	--	--	0.311	37	2
	155	84.3	--	--	0.311	37	2
	160	84.1	--	--	0.312	37	2
	165	84.0	--	--	0.312	37	2
	170	83.9	--	--	0.312	37	2
	175	83.5	--	--	0.313	37	2
	180	83.3	--	--	0.313	37	2
	185	83.0	--	--	0.314	37	2
	190	82.9	--	--	0.314	37	2
	195	82.7	--	--	0.314	37	2

1 Static measurement.

2 Dynamic measurement.

## 4. THERMAL PROPERTIES

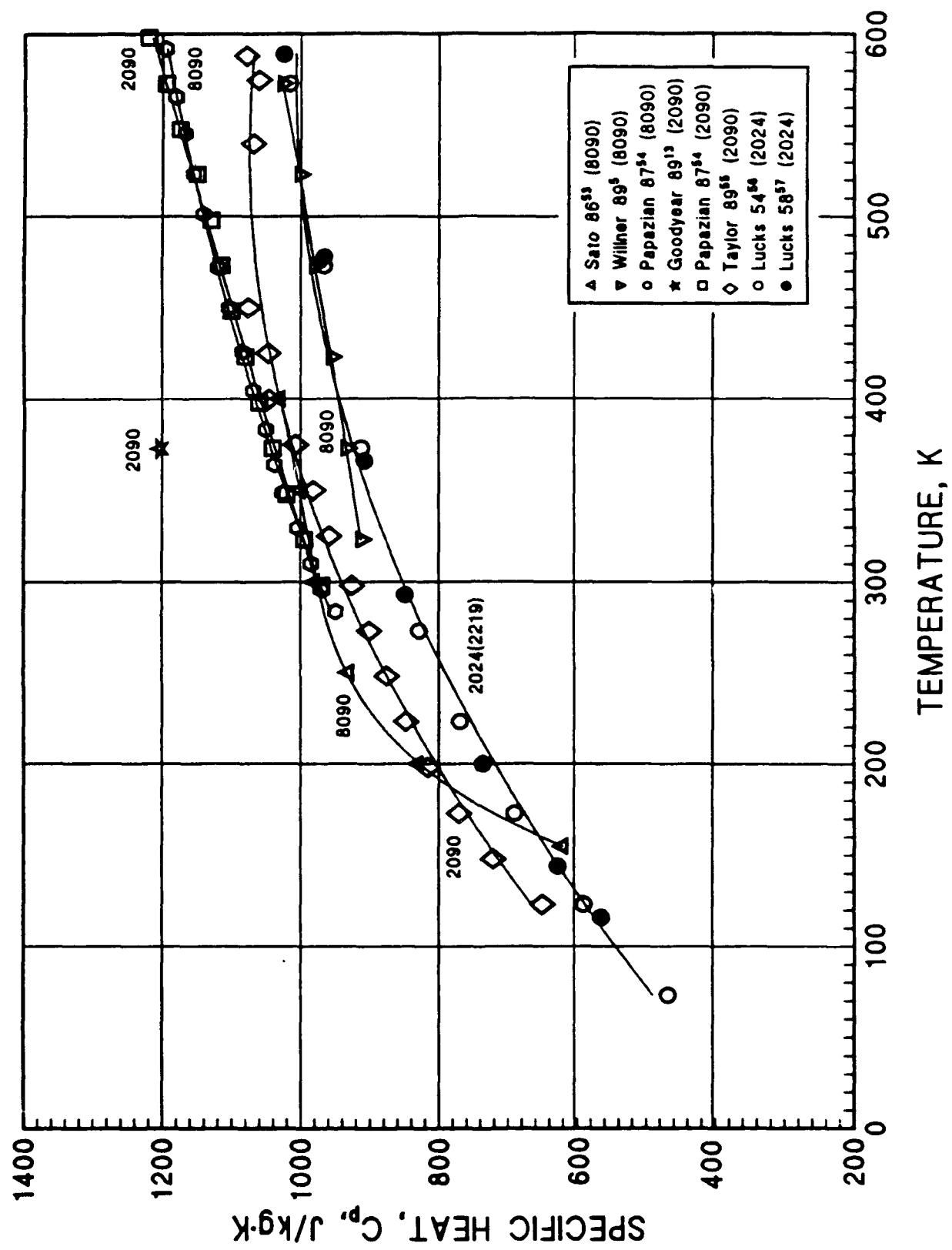
### 4.1. Specific Heat

#### 4.1.1. Introduction to Graph

The available specific heat ( $C_p$ ) data from cryogenic temperatures to the melting point are presented in the figure and table. Measurements are available only on alloys 8090 and 2090 between 123 and 598 K. Some of these data were obtained by differential scanning calorimetry to indicate the dissolution temperature of precipitates produced by various aging treatments and the formation of subsequent phases. These are shown in a smoothed form,<sup>53,54,55</sup> or are omitted<sup>53</sup> above 400 K. As shown by Papazian,<sup>54</sup> changes in the aging treatment move the position of the peaks and valleys along the curve to higher and lower temperatures. Taylor<sup>55</sup> identified the peak at ~510 K in his specific heat data as the melting point of Li. However, a peak at this position is not observed in the other specific heat measurements of alloy 2090, and it seems more probable that peaks can be identified with the aging treatment. Consult the original references, which specify aging treatments, for specific heat data on alloys 8090 and 2090 with the fine structure in the curves (important only above 400 K).

At present, there are no specific heat data for alloys WL049 or 2219 in the cryogenic temperature range. The curve for the specific heat of alloy 2219 vs. temperature presented in Figure 3.2.6.0. of MIL-HDBK 5E<sup>2</sup> appears to be based upon data from Al-alloy 2024.<sup>56,57</sup> The composition of alloy 2024 (4.5Cu, 1.5Mg, and 0.6Mn), is similar to the composition of alloy 2219 (5.8–6.8Cu, and 0.2–0.4Mn). These data, labeled 2024(2219), are also given in the figure.

The specific heat of an alloy can be approximated, near ambient temperature, by a linear combination of the specific heats of the constituent elements.<sup>58</sup> Because the specific heat of Li is about 4 times larger than the specific heat of Al, and about 9 times larger than that of Cu, the specific heats of alloys 8090 and 2090 should be about 10% higher than that of alloy 2219. This is similar to what is shown in the specific heat figure for the data of Sato<sup>53</sup> on alloy 8090 and Papazian<sup>54</sup> on alloy 2090. However, the higher temperature data on alloy 8090<sup>4</sup> appear quite similar to that of alloy 2024(2219), and, therefore, are probably too low. Variations in aging conditions and chemistry for individual heats can result in changes in the fine structure of a specific heat curve for Al-Li alloys, especially above ambient temperatures. This could account for this apparent discrepancy, and perhaps, also for one unexpectedly high value of specific heat<sup>12</sup> at 100 °C. More measurements of the specific heat on current production heats of Al-Li alloys would be very desirable.



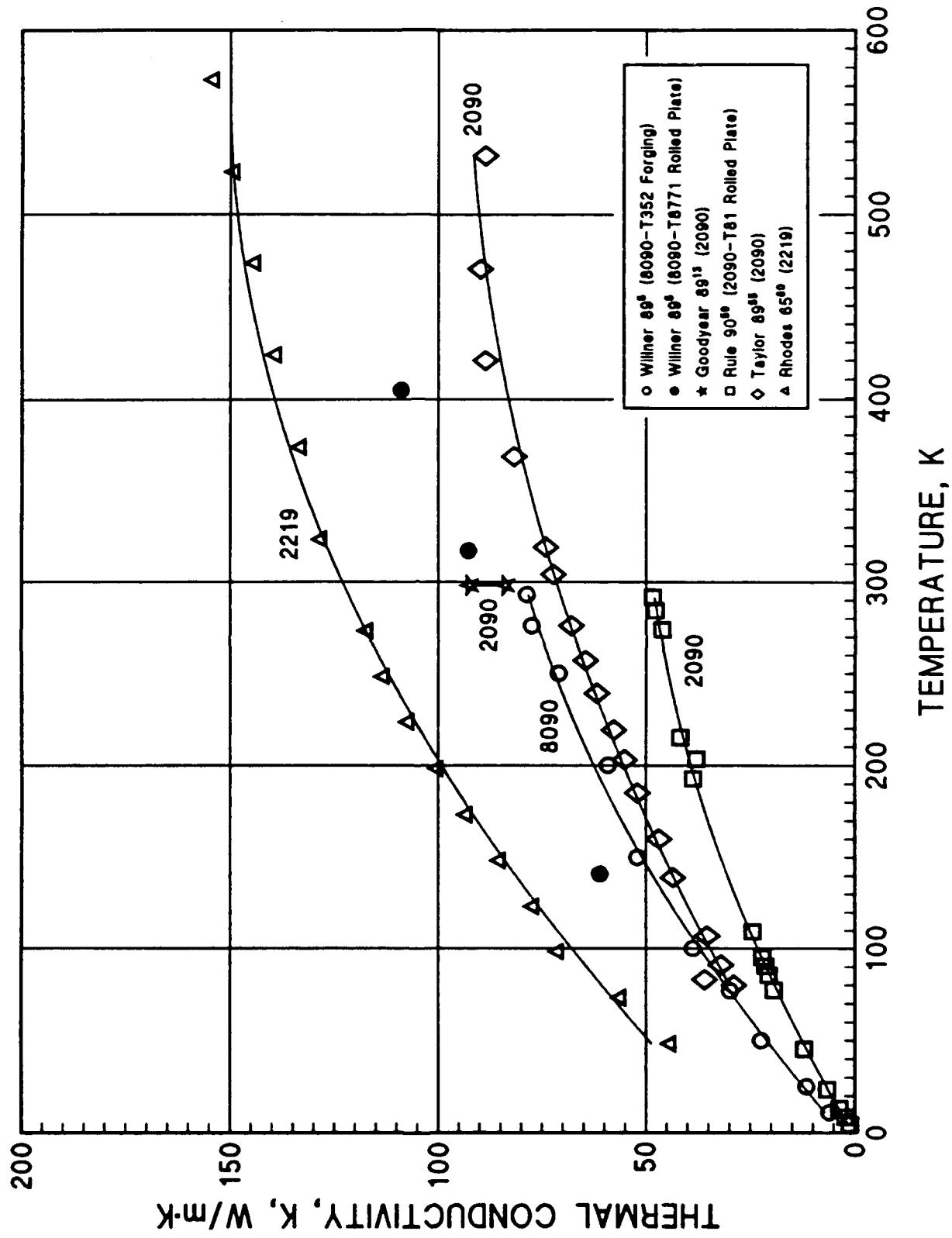
Specific Heat of Al-Li Alloys and Alloy 2219.

Alloy	Temp., K	$C_p$ , J/kg·K	Ref. No.	Alloy	Temp., K	$C_p$ , J/kg·K	Ref. No.	
8090	155	620	54	2090	123	649	56	
	200	830	54		148	720	56	
	250	930	54		173	770	56	
	300	980	54		198	815	56	
	350	1000	54		223	847	56	
	400	1030	54		248	875	56	
	323	913	5		273	900	56	
	373	934	5		298	925	56	
	423	956	5		325	958	56	
	473	980	5		350	981	56	
8090	523	1002	5		375	1006	56	
	573	1027	5		400	1045	56	
	623	1047	5		425	1046	56	
	673	1070	5		450	1075	56	
	284	949	55		540	1068	56	
	296	969	55		575	1060	56	
	310	985	55		588	1078	56	
	329	1005	55	2024(2219)	73	469	57	
	349	1026	55		123	590	57	
	364	1038	55		173	690	57	
8090	383	1051	55		223	770	57	
	404	1069	55		273	828	57	
	426	1085	55		373	912	57	
	450	1104	55		473	967	57	
	472	1120	55		573	1017	57	
	501	1141	55		2024(2219)	116	565	58
	523	1155	55		144	628	58	
	546	1168	55		200	736	58	
	566	1181	55		293	849	58	
	592	1195	55		366	908	58	
2090	373	1203	13		478	966	58	
	298	970	55		589	1025	58	
2090	323	995	55					
	348	1020	55					
	373	1040	55					
	398	1060	55					
	423	1080	55					
	448	1100	55					
	473	1115	55					
	498	1130	55					
	523	1150	55					
	548	1175	55					
	573	1195	55					
	598	1220	55					

## 4.2. Thermal Conductivity

### 4.2.1. Introduction to Graph

Thermal conductivity (K) data for alloys 8090, 2090, and 2219 between 4 and 573 K are given in the accompanying thermal conductivity figure and table. No data on WL049 are currently available. The solid lines shown in the figure represent the fit of second-order polynomials to the alloy 8090,<sup>4</sup> alloy 2090,<sup>53,59</sup> and alloy 2219<sup>60</sup> data. The data of Rule<sup>59</sup> appear to be anomalously low. However, thermal conductivity of Al alloys at low temperatures is composition and cold-work sensitive.<sup>61</sup>



Thermal Conductivity of Al-Li Alloys and Alloy 2219.

Alloy	Temp., K	K, W/m·K	Ref. No.	Alloy	Temp., K	K, W/m·K	Ref. No.
8090-T352	11	6.1	5	2090	80	28.8	56
	25	11.6	5		83	35.8	56
	50	22.5	5		91	31.9	56
	77	29.9	5		107	35.2	56
	100	38.8	5		139	43.4	56
	150	52.1	5		160	46.7	56
	200	59.2	5		185	51.9	56
	250	71.0	5		203	55.0	56
	276	77.5	5		219	57.6	56
	293	78.7	5		239	61.7	56
8090-T8771	141	61.1	5	2219	257	64.4	56
	317	92.8	5		276	67.8	56
	404	109.	5		304	72.2	56
2090	298	87.9	13		319	74.0	56
2090-T81	4	1.1	60		368	81.6	56
	8	2.2	60		420	88.5	56
	13	3.6	60		470	89.7	56
	23	6.6	60		532	88.5	56
	45	12.1	60		48	44	61
	77	19.4	60		73	56	61
	85	20.6	60		98	71	61
	90	21.4	60		123	77	61
	95	22.1	60		148	85	61
	109	24.4	60		173	93	61
	193	38.6	60		198	100	61
	203	37.9	60		223	107	61
	215	41.7	60		248	113	61
	274	46.1	60		273	117	61
	284	47.7	60		323	128	61
	292	48.4	60		373	133	61
					423	139	61
					473	144	61
					523	149	61
					573	154	61

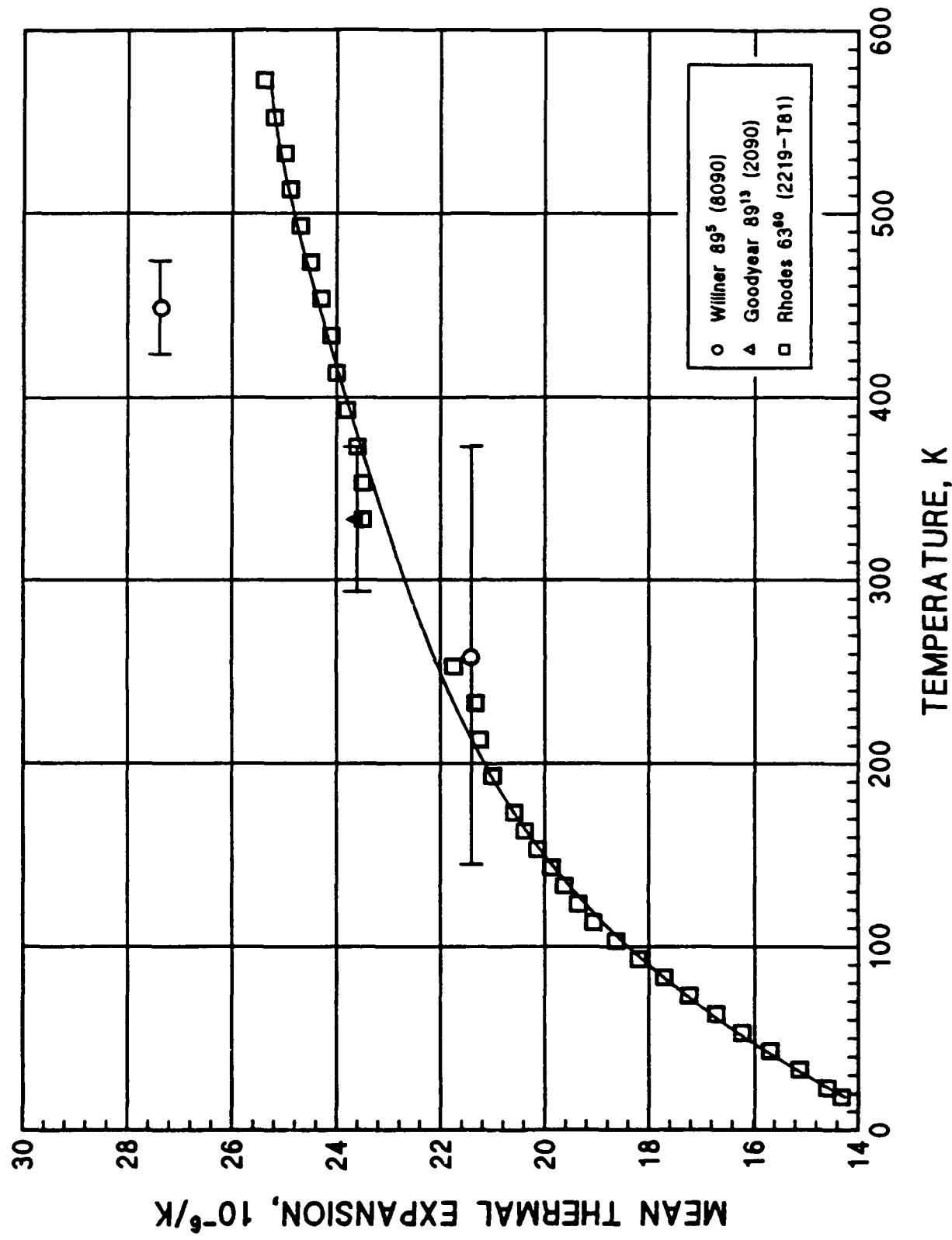
#### 4.3. Mean Thermal Expansion

##### 4.3.1. Introduction to Graph

The figure on mean thermal expansion presents the data available on the property, defined as:

$$\Delta L/L \cdot \Delta T = [L(293 \text{ K}) - L(T)]/[L(293 \text{ K}) (293 \text{ K} - T)].$$

Only data for alloy 2219-T87 are available over a wide temperature range, from 18 to 573 K. The values presented for alloys 8090 and 2090 are averages obtained over the temperature range indicated in the graph. Near 293 K, the quantity  $\Delta L/L \cdot \Delta T$  becomes less accurate, because a smaller length change is measured. Mean thermal expansion data for alloy 2219 near 293 K were eliminated if a wide degree of scatter was evident. Although only one set of thermal expansion data for alloy 2219 is available, that data set is in reasonable agreement with several sets of data for alloy 6061 (0.6 Si, 0.27 Cu, 1.0 Mg, 0.2 Cr) over a similar temperature range. The data are also presented in the thermal expansion table that follows the graph.



Mean Thermal Expansion of Al-Li Alloys and  
Alloy 2219.

Alloy	Temp., K	$\frac{1}{L} \frac{\Delta L}{\Delta T}$ , $10^{-5} K^{-1}$	Ref. No.
8090	258	27.4	5
	448	21.4	5
2090	333	23.6	13
2219-T81	18	14.3	61
	23	14.6	61
	33	15.1	61
	43	15.7	61
	53	16.2	61
	63	16.7	61
	73	17.2	61
	83	17.7	61
	93	18.2	61
	103	18.6	61
	113	19.1	61
	123	19.4	61
	133	19.6	61
	143	19.9	61
	153	20.1	61
	163	20.4	61
	173	20.6	61
	193	21.0	61
	213	21.3	61
	233	21.3	61
	253	21.8	61
	333	23.5	61
	353	23.5	61
	373	23.6	61
	393	23.8	61
	413	24.0	61
	433	24.1	61
	453	24.3	61
	473	24.5	61
	493	24.7	61
	513	24.9	61
	533	25.0	61
	553	25.2	61
	573	25.4	61

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